

DOCUMENT RESUME

ED 215 187

CE 032 015

AUTHOR Green, Joanne; And Others
TITLE Solar Heating Systems: Instructor's Guide.
INSTITUTION Georgia Inst. of Tech., Atlanta. Engineering
Experiment Station.
SPONS AGENCY Georgia State Dept. of Education, Atlanta. Office of
Vocational Education.
PUB DATE 79
NOTE 312p.; For related documents see CE 032 016-017.
EDRS PRICE MF01/PC13 Plus Postage.
DESCRIPTORS Course Content; Curriculum Guides; Guidelines;
*Heating; *Instructional Materials; Learning Modules;
Postsecondary Education; Secondary Education; Slides;
*Solar Radiation; Teaching Guides; *Teaching Methods;
*Technical Education; Vocational Education

ABSTRACT

This Instructor's Guide for a Solar Heating System Curriculum is designed to accompany the Student Manual and the Progress Checks and Test Manual for the course (see note), in order to facilitate the instruction of classes on solar heating systems. The Instructor's Guide contains a variety of materials used in teaching the courses, including answers for all questions asked on Assignment Sheets, Progress Checks, and Unit Tests; copies of the scripts that accompany all of the non-commercially produced slide shows provided for the program; and instructions for teacher demonstrations. The materials are organized by unit, in order of their use. The guide also contains explanations of teacher observation requirements and the uses of Progress Checks. The four modules of the solar heating system curriculum cover the following topics: (1) understanding solar systems; (2) designing solar systems; (3) installing solar systems; and (4) maintenance of solar systems. Twenty-two units are contained within the four major modules. (KC)

* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *

ED215187

CE 032 015

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)

☒ This document has been reproduced as
received from the person or organization
originating it.

☐ Minor changes have been made to improve
reproduction quality.

• Points of view or opinions stated in this docu-
ment do not necessarily represent official NIE
position or policy.

"PERMISSION TO REPRODUCE THIS
MATERIAL HAS BEEN GRANTED BY

A. Maughon

TO THE EDUCATIONAL RESOURCES
INFORMATION CENTER (ERIC)."

Developed by

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia 30332

Written by:

Joanne Green

Esther Lee Davenport

Joe N. Harris

Graphics designed:

Claude Lattimore

Under Contractual Agreement With

Division of Program Development
Office of Vocational Education
Georgia Department of Education
Atlanta, Georgia 30334
Charles McDaniel, State
Superintendent of Schools
1979

SOLAR HEATING SYSTEM'S CURRICULUM
INSTRUCTOR'S GUIDE

Each instructor should have copies of three manuals:

- 1) The Student Manual
- 2) The Instructor's Guide
- 3) Progress Checks and Test Manual

The Instructor's Guide contains a variety of materials used in teaching, including the following:

- 1) Answers for all questions asked on Assignment Sheets, Progress Checks, and Unit Tests
- 2) Copies of the Scripts that accompany all of the non-commercially produced slide shows
- 3) Instructors for Teacher Demonstrations

These materials are organized by unit, in the order of their use.

EXPLANATION OF INSTRUCTOR OBSERVATIONS

The instructor is encouraged to observe student progress as frequently as s/he believes is necessary. The solar system curriculum specifies points at which it is believed that observation of student activities is particularly important. In many cases the teacher is to observe the outcome of a just-completed activity, such as answering a difficult set of study questions. In such cases, the instructor should check student answers, and make sure that the student understands the answers, and how they were reached. Other observations ask the instructor to observe an on-going activity such as a student verbal presentation or the construction of a part of a solar system. These observations are not designed for grading, but rather as points at which student progress can further be checked.

Explanation of Progress Checks

Each unit contains several Progress Checks. These are points at which student understanding of recent activities is evaluated. Progress checks are particularly important in checking student comprehension and learning where previous activities have involved the reading of somewhat technical material.

Each Progress Check requires the student to answer a set of questions, some of which may be from the study questions associated with activities since the last Progress Check. The Progress Check must be passed at the 80 percent level. If not, the student must review the appropriate activities for retaking that Progress Check. The instructor keeps a record of which students have passed which Progress Check. This information is recorded on a Class Progress Chart, which all students can view. A Class Progress Chart such as this helps students to pace themselves, and motivates less ambitious students to work harder. It also helps to identify students who may need special assistance.

The instructor also keeps a private record of Progress Check failures, so that these students can be offered assistance.

There are several types of Progress Checks. The Unit Sheet recommends a specific type of Progress Check, but the instructor is free to use his/her own judgment of the most appropriate type. The type of Progress Checks are listed below:

Teacher Oral Quiz - The instructor asks questions, which the student answers orally. The instructor gives immediate feedback on each response.

Teacher Written Quiz - The instructor assigns questions to be answered in writing, and evaluates the answers.

Peer Quiz - The student is assigned by the instructor to a fellow student who has passed that Progress Check, and who gives an oral quiz.

Self-Graded Quiz - The instructor assigns questions, which the student answers in writing. The student obtains an answer sheet, and grades his/her own quiz. The instructor occasionally checks the accuracy of student grading.

All of these Progress Checks examine student comprehension and learning. They differ somewhat in special skills which they

foster. The Peer Quiz and Teacher Oral Quiz encourage the development of oral abilities. Those skills are important when the solar system technician must explain the solar system to a customer. The Peer Quiz encourages students to work together and to help each other. The Self-graded Quiz encourages self-reliance and the evaluation of one's own progress. Both the Teacher Written Quiz and the Self-graded Quiz foster written verbal abilities and clarity of expression.

TABLE OF CONTENTS

<u>Unit</u>	<u>Task</u>	<u>Page</u>
SA-1	Explain the value of solar energy and principles of solar radiation.	1
	Script: Solar Energy: Energy for the Future	17
	Script: Solar Energy: Basic Terms and Principles	23
SA-2	Describe basic solar system components and their functions.	33
	Script: Basic Components of Residential Solar Installations	45
SB-1	Recommend non-solar energy conservation measures.	53
SB-2	Select passive solar approaches for new construction.	63
	Script: Passive Solar Approaches: How Well Do They Work?	91
SB-3	Recommend collectors.	101
	Script: Flat Plate Solar Collectors: Factors Affecting Function (Part I)	117
	Script: Flat Plate Solar Collectors: Factors Affecting Function (Part II)	123
SB-4	Recommend and site the thermal storage unit.	127
SB-5	Recommend control devices.	145
SB-6	Recognize and describe modes of solar system operation.	157
	Script: Operation of Liquid Solar Heating Systems	167
SB-7	Calculate heat load for space or domestic hot water heating.	177
SB-8	Size solar system components.	195

TABLE OF CONTENTS (CONCLUDED)

<u>Unit</u>	<u>Task</u>	<u>Page</u>
SB-9	Perform a solar system economic analysis.	209
SB-10	Recommend a domestic hot water system.	221
	Script: Solar Domestic Hot Water Systems: Some Examples	229
SC-1	Recommend correct thermal mass for direct gain system; fabricate and install modular wall units for passive solar.	233
SC-2	Schedule solar installation.	241
	Script: Steps in Liquid System Installation	247
SC-3	Install a liquid storage tank.	253
SC-4	Site and mount collectors.	257
SC-5	Install liquid collectors and outside plumbing.	265
SC-6	Install inside plumbing for collector load side loops.	279
SC-7	Install controls and wiring.	289
SC-8	Start up system.	295
SD-1	Maintain the solar system.	301
SD-2	Troubleshoot solar system problems.	305

Solar Vs Conventional Energy

1) Define the following terms:

- a. nonrenewable resource - a natural resource whose supply is limited, and will eventually be depleted; for example, coal, oil, natural gas
- b. photovoltaic cell - a solar device capable of converting solar energy directly to electricity
- c. thermal pollution - pollution by overheating. For example, hot nuclear power plant wastes are dumped into the sea, heating the water to a point which damages the marine life

- 2) Pretend you are a salesperson for a company that designs, installs and services solar heating systems. You are planning an important meeting with a building contractor who is choosing heating systems for a twenty house subdivision. In the space below, list the points you would make to inform him about the disadvantages of using conventional fuels, and the advantages of solar systems, relative to conventional systems. Also, list possible objections to solar systems which the contractor might make, and indicate your response to overcoming each objection.

After you have outlined your argument, try it out by presenting it to a fellow student, who should assume the role of the building contractor. Ask your instructor to observe your presentation, and evaluate it.

Advantages of solar systems relative to conventional systems:

1. Solar energy is unlimited in supply, while conventional fuels are limited.
2. Use of solar energy does not pollute the environment, as do conventional fuels.
3. Solar energy is free, while the costs of conventional fuels are accelerating rapidly.

Possible objections to solar systems and responses to objections:

1. The price of solar system equipment is high, because the technology is new, and back-up heating systems are necessary.

Counter argument--The cost of solar equipment will go down when there is greater demand for solar equipment.

(Continued on next page)

Disadvantages of conventional fuels:

1. They are non-renewable, and will eventually be used up.
2. Their use pollutes the atmosphere.
3. They are rapidly rising in cost as supplies decrease.

Although the initial investment is high, a well-designed solar system will reduce the use of costly conventional fuels. Over time these savings will pay back the system's initial cost.

2. Large areas are necessary for mounting collectors.

Counter argument--In a well-designed system, the collectors are mounted on the roof or ground in an unobtrusive and attractive manner.

3. The sun's energy is not always available.

Counter argument--Solar systems always include a back-up heating system to supply heat when solar energy is unavailable. A solar system also includes a heat storage unit which stores heat for use when there is little direct solar energy available.

SOLAR ENERGY: BASIC TERMS

- 1) Indicate whether each of the following illustrates heating primarily by radiation, conduction, or convection.
 - a. radiation The top of our head becomes hot when standing in the sun.
 - b. conduction The bottom of a pot becomes hot when placed on an electric stove burner.
 - c. radiation Our hands are warmed by holding them over an electric burner.
 - d. convection A small room space heater on the floor gradually heats all of the air in the room.
 - e. convection The air in the north-most half of a room is warmed by sunshine which warms the floor only on the south side of the room.
 - f. radiation A room filled with people gradually becomes warmer.
- 2) Define the following terms:
 - a. solar constant - the constant amount of solar energy hitting the earth's outer atmosphere. Is equal to $429.2 \text{ Btu/hr/ft}^2$
 - b. Btu - British thermal unit, a measure of heat energy. Is the amount of heat necessary to raise the temperature of 1 pound of water by 1° F .
 - c. insolation - the solar radiation which hits the earth's surface
 - d. pyrheliometer - an instrument used to measure heat energy from the sun

DETERMINING SOLAR TIME

Problems:

- a. What is the longitude for your area? _____
- b. Determine the local solar time when it is 12 noon, clock time in May.

Calculate the total correction factor. Solar noon is this amount of time different from clock noon. Add or subtract this time from noon, depending on your location.

- c. What clock time corresponds to solar noon in Atlanta in July?

The example given on Information Sheet SA-1-1 demonstrated that clock time was ahead of solar time by a total of 104 minutes. So, in Atlanta in July, solar noon occurs 104 minutes after clock time noon.

$$12 \text{ noon} + 104 \text{ min} = 1:44 \text{ PM}$$

Solar noon occurs when clock time is 1:44 PM.

- d. What clock time corresponds to solar noon in your area in May?

FACTORS AFFECTING INSOLATION

1) Define the following terms:

- a. solar noon - the time when the sun is most directly overhead. Is usually different from clock time noon.
- b. direct radiation - has travelled in uninterrupted, straight parallel rays directly from the sun.
- c. diffuse radiation - has been scattered by materials in the atmosphere
- d. latitude - a measure of the distance of a location to the north or south of the equator
- e. longitude - a measure of the east-west position of a location

- 2) Is there more insolation in summer or in winter? Why?
- in summer--the sun is more directly overhead, allowing more direct radiation to reach the earth

- 3) Is there more insolation on a sunny or cloudy day? Why?
sunny day--there are fewer clouds to diffuse the
sun's radiation

- 4) Is there more insolation at clock time noon or solar noon?
Why?
solar noon--that is when the sun is really most directly
overhead, allowing more direct radiation to reach the
earth

- 5) Which receives more solar radiation, the earth's outer
atmosphere or the earth's surface? Why is this so?
outer atmosphere--the atmosphere absorbs and scatters
radiation before it reaches the earth

- 6) How much heat energy is absorbed by a surface that is 20 x 30
feet at noon on a clear day? Show your calculations.

$$\text{area} = 20 \times 30 = 600 \text{ ft}^2$$

$$600 \text{ ft}^2 \times 290 \text{ Btu/h/ft}^2 = 174,000 \text{ Btu/h}$$

PART A

Match each term with its definition:

- 3 a. nonrenewable energy source
- 1 b. photovoltaic
- 5 c. direct radiation
- 10 d. diffuse radiation
- 2 e. insolation
- 9 f. solar constant
- 7 g. renewable energy source
- 6 h. Btu
- 4 i. pyrheliometer
- 8 j. latitude
- 11 k. convection

- 1. Converts solar radiation to electricity.
- 2. The solar energy which reaches the earth's surface.
- 3. Will someday be all used up.
- 4. Used to measure heat energy.
- 5. Is uninterrupted in its path to the earth.
- 6. Amount of heat necessary to increase the temperature of one pound of water one degree Fahrenheit.
- 7. Is of unlimited quantity.
- 8. Indicates the distance from the sun's equator.
- 9. The amount of solar energy striking the outer atmosphere which varies only slightly.
- 10. Is scattered as it travels through the atmosphere.
- 11. Heat transfer that occurs in fluids because heated fluids are lighter and rise.

PART B

1. At what time of day is solar insolation the greatest?
at solar noon (6 points)
2. List two points with regard to each of the following topics:
 - a. Problems with conventional fuels:
 1. pollute environment, limited supply, costly
 - 2.
 - b. Advantages of solar energy:
 1. Non-polluting, free, unlimited supply (4 points each)
 - 2.
3. Why is the radiation received on earth less than that hitting the outer atmosphere?
Radiation is absorbed and scattered as it travels through the atmosphere. (6 points)
4. What have you found most interesting so far in this unit?
(6 points)

SITING SOLAR COLLECTORS

- a. Calculate the appropriate tilt angle for solar collectors in Albany, GA. (latitude 31.5°) for the following applications: Show your calculations below.

Solar heating only: $31.5 + 15 = 46.5^{\circ}$

Solar cooling only: $31.5 + 15 = 16.5^{\circ}$

Solar hot water: 31.5°

- b. What is the azimuth angle?

The azimuth angle describes the angle between the collector orientation and true south, or the position of the sun at solar noon.

- c. In the northern hemisphere, why should solar collectors be positioned facing south?

The collector receives the greatest total amount of radiation over a day if it faces south.

- d. If the solar collectors are oriented 15° west of south, will maximal solar radiation be collected before or after solar noon? Why?

After solar noon--The sun's rays will be more direct, and will travel a shorter path after solar noon.

Answer the following questions:

- a. You are a solar system designer, and you must choose a single tilt angle for a collector. You want to maximize the amount of direct energy received by your collector during each day of the current season. What tilt angle would you choose? Explain your choice.

Choose the tilt angle for optimal insolation at solar noon. The average insolation for the day is greatest when this tilt angle is used. Tilt angles that are optimal at other times of the day do not allow maximal gathering of energy when the sun is most directly overhead.

- b. Would the tilt angle chosen above need to be adjusted during other seasons? Why or why not?

The sun's position in the sky at solar noon varies with the season. The tilt angle must be adjusted so that the energy collecting surface is perpendicular to the direct sun's rays at solar noon during the season in which the most energy must be collected.

CONVERTING UNITS OF MEASUREMENT

You may encounter situations in which you will want to convert quantities of energy expressed in one unit of measurement to another unit of measurement. Recall that a British Thermal Unit (Btu) is the amount of heat required to raise the temperature of 1 pound of water by 1° F.

Perform the following conversions. Show your calculations. You may refer to the conversion factors in the previous reading assignment.

a. 220 Langleys = 811.8 Btu/ft²

b. 721 KJ/m² = 63.4 Btu/ft²

c. 73 Langleys/min = 16,133 Btu/ft²/hr

d. 311 KJ/m²/hr = 27.4 Btu/ft²/hr

e. 110 w/m² = 34.8 Btu/ft²/hr

1. List two advantages of solar energy systems.
 - a. They use an unlimited resource.
They are non-polluting.
The energy is free.
 - b.
2. Two examples of nonrenewable resources are _____ and _____.
(coal, oil, natural gas, uranium)
3. A photovoltaic cell is a device which converts solar energy to electricity.
4. What is the value of the solar constant? 428.7 Btu/ft²/h
5. The instrument used to measure solar insolation is called a pyreheliometer.
6. The kind of radiation which produces maximal heat energy is called direct radiation.
7. 290 Btu/ft²/hr are received on earth at noon on a sunny day.
8. When heat energy travels from one area to another as the heated fluids rise, this is known as convection.
9. Identify each of the following as examples of conduction, convection, or radiation:
 - radiation a. The street becomes hot on a sunny day.
 - conduction b. If we hold a marble in our hand, it becomes warm.
10. The maximal insolation during a day is received at solar noon.

11. In the northern hemisphere, solar collectors should be oriented so they face true south.
12. The north walls of a building in the northern hemisphere receive diffuse radiation, but not direct radiation.

13. What is a British thermal unit?
the amount of heat necessary to raise the temperature of 1 pound of water by 1° F.

14. Define insolation.

The solar radiation which hits surfaces on earth.

15. Why is less radiation received on earth than that hitting the earth's outer atmosphere?

The atmosphere absorbs and scatters radiation.

16. For a location at a 30° latitude, what collector tilt angle would you recommend for:
- a. space heating only $30 + 15 = 45^{\circ}$
- b. heating domestic hot water only 30°

17. Using Information Sheet A-1-1, calculate the solar time at 4 P.M. in January for a location which is in the Eastern Time Zone, and which has a longitude of 70° . (4 points)

Step 1: no correction for D.S.T

Step 2: difference between local longitude and time zone

$$\text{meridian} = 75^{\circ} - 70^{\circ} = 5^{\circ}$$

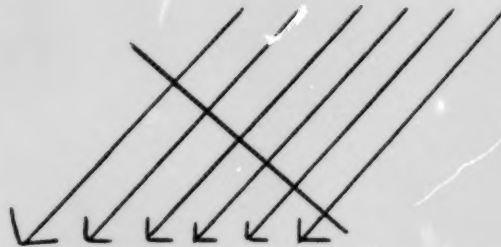
$$5^{\circ} \times 4 \text{ minutes/degree} = 20 \text{ minutes}$$

The locality is east of the meridian so, 4 P.M. - 20 minutes = 3:40 P.M.

Step 3: correct by -11 minutes: $3:40 - 11 = 3:29$ P.M.

So, clock time 4 P.M. = solar time 3:29 P.M.

18. In the drawing below, illustrate how you would tilt a surface to capture maximal solar radiation. (4 points)

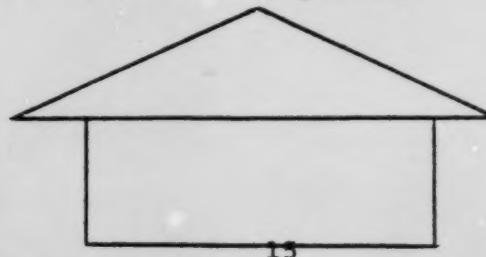


Tilt the surface perpendicular to the rays.

19. Why does the tilt angle appropriate for maximal insolation vary with the season? (4 points)

The sun is higher in the sky in the summer than in the winter, so the angle of the sun's rays differs with the season. The tilt angle for maximal insolation in a season should allow the rays to hit the surface in a perpendicular fashion.

20. In the diagram below, show how the overhang affects the path of the sun's rays to shade the house in the summer, but not in the winter. (4 points)



21. Why do you think that people are reluctant to install solar energy systems in their homes?

SOLAR ENERGY: ENERGY FOR THE FUTURE

SLIDE #1 (VMC title slide)

(Music up for about five to ten seconds. . .then down under next frame's narration.)

SLIDE #2 (Title slide: Solar Energy, Energy for the Future)

In the past, our country has relied on oil, coal, natural gas, and wood as major energy sources. In times to come, solar energy will be the energy for the future. Let's examine why this change will occur.

SLIDE #3 (Photo of winter weather)

Do you remember the winter of '73? 1973, that is. During that winter the oil producing countries of the Middle East limited oil sales to the U.S. This left us with insufficient supplies of one of our primary energy sources--oil.

SLIDE #4 (Drawing of cars lined up; closed factories)

So, we waited in long lines for limited supplies of gasoline. Many lost their jobs as factories closed. And we all shivered as we watched rising fuel costs, and lowered our thermostats to conserve energy.

SLIDE #5 (Graph of sources of U.S. energy)

The oil embargo of 1973 forced us to be more aware of our energy resources, and their limits. Our major resources are oil, gas, and coal. More recently, interest in nuclear energy, which requires uranium, has grown. Unfortunately, each of these energy sources--oil, gas, coal, and uranium is associated with specific problems.

SLIDE #6 (Graph of supplies of energy sources)

Each of these energy sources is available in only limited quantities, which will be used up in the comprehensible future. Oil, gas, coal and uranium are therefore referred to as non-renewable energy sources.

SLIDE #7 (Graph of increase in energy demand over time)

Even as the supplies of conventional energy sources become more limited, it is predicted that the demand for energy will continue to grow.

SLIDE #8 (Graph of increase in fuel costs over time)

As the demand for energy grows, and energy sources grow more limited, the cost of oil, gas, coal, uranium, and electricity will accelerate even faster.

SLIDE #9 (Illustration of polluted environment)

High cost and limited quantities are not the only problems with these energy sources. They also contribute to several kinds of environmental problems. When burned for energy, both oil and coal contribute to air pollution, which makes breathing difficult and causes deterioration of the protective atmosphere which surrounds the earth.

SLIDE #10 (Illustration of thermal pollution)

The liquid exhaust from power plants using coal, gas, or uranium is often so hot that it harms the fish and vegetation into which the hot liquid is dumped. This is called thermal pollution.

SLIDE #11 (Photo of nuclear power plant)

Nuclear energy, the most recently developed energy source, presents its own unique set of safety concerns. In particular, there is the problem of how to dispose of the highly radioactive nuclear wastes. Such wastes cause cancer and other severe health problems.

SLIDE #12 (Photo of sunset)

We do, however, have an energy source which is largely untapped, and which has none of the previously discussed problems.

SLIDE #13 (Photo of heat on beach)

The sun radiates energy, which generates heat, as all of us know.

SLIDE #14 (List of positive aspects of solar energy)

Solar energy will be available as long as the sun shines, and at no charge.

SLIDE #15 (Photo of pretty country scene)

Use of solar energy to generate heat causes minimal environmental pollution.

SLIDE #16 (Photo of windmill)

Solar energy has already been harnessed in a variety of ways. Electricity has been produced by windmills, which really take advantage of a form of solar energy. The sun heats the air on earth, causing it to rise and create the air currents which power the windmills.

SLIDE #17 (Drawing of photovoltaic cell operation)

Photovoltaic cells directly absorb the sun's radiation to produce electricity.

SLIDE #18 (Photo of photovoltaic panel)

Panels of photovoltaic cells can be used to provide power in remote areas where electricity is unavailable.

SLIDE #19 (Illustration of how energy is used)

Solar energy can also be used to heat and cool buildings, and to heat water. Heating and cooling consume a significant amount of the total energy we use. Greater and better use of solar energy for heating and cooling would decrease our need for other, more problematic energy sources.

SLIDE #20 (Photo of solar equipment)

Why, then, are solar heating systems not used more widely? Unfortunately, being a new technology, solar heating systems are relatively costly to install, even though the sun's energy is free.

SLIDE #21 (Photo of collector array)

Large areas of solar energy collectors are necessary for collecting the solar energy that will generate heat.

SLIDE #22 (Photo of storage unit)

The sun cannot always provide energy, as on cloudy days or at night. Therefore, solar systems must include heat storage units, and conventional backup heating systems, increasing the cost of solar systems.

SLIDE #23 (Photo of solar house)

However, solar systems will become more economical as the price of conventional fuels increases, and as solar technology becomes more popular.

SLIDE #24 (Photo of solar community)

Solar systems will also become more widely adopted when there are more people available who are trained to explain, design, and properly install effective solar systems.

SLIDE #25 (Illustration of solar energy)

This course will train you in the principles and operation of solar heating and cooling systems. Your knowledge and application of it will allow you to contribute to the solution of the energy problem.

NARRATION SCRIPT

SOLAR ENERGY: BASIC TERMS & PRINCIPLES

SLIDE #1 (VMC Title Slide)

(Music up for about 5 to 10 seconds...then down under next frame's narration)

SLIDE #2 (Title: SOLAR ENERGY BASIC TERMS AND PRINCIPLES)

To understand the actual operation of solar heating and cooling systems, you must first be familiar with basic terms and principles associated with solar energy.

SLIDE #3 (PHOTO OF SUNSET)

You might ask, how is it that the sun produces heat on earth?

SLIDE #4 (DRAWING OF SUN RADIATING ENERGY)

The sun radiates, or gives off, vast quantities of energy in the form of energy waves or solar radiations.

SLIDE #5 (DRAWING OF ELECTROMAGNETIC SPECTRUM)

The energy waves vary in their wavelength. Energy of medium wavelength is visible to the human eye, and lights surfaces which it strikes. These "visible" wavelengths comprise only a small proportion of the energy waves emitted by the sun.

SLIDE #6 (DRAWING OF ELECTROMAGNETIC SPECTRUM, HIGHLIGHTING
LONG & SHORT WAVES)

Relatively short or long wavelength are invisible to the human eye when they strike the earth.

SLIDE #7 (GRAPH OF BTU'S PRODUCED BY DIFFERENT PARTS OF SPECTRUM)

Even though not all solar radiation is visible to the eye, all of the solar wavelengths produce heat energy when they strike material in the atmosphere or on earth. The shorter wavelengths are largely absorbed by the atmosphere, so medium and longest wavelengths are responsible for most of the solar heating on earth.

SLIDE #8 (BRITISH THERMAL UNIT)

A basic unit of heat energy is the British thermal unit, or B.t.u.

SLIDE #9 (ILLUSTRATION OF THE MEANING OF BTU)

A B.t.u. is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

SLIDE #10 (ILLUSTRATION OF CONCEPT OF BTU (FT²))

We refer to the amount of heat generated on a surface on earth in terms of number of B.t.u.'s per square foot.

SLIDE #11 (ILLUSTRATION OF CONCEPT OF BTU/FT²/HR)

The amount of energy generated in a given period of time is discussed in terms of number of B.t.u.'s per square foot per hour.

SLIDE #12 (ILLUSTRATION OF PYRHELIOMETER)

The instrument used to measure solar heat energy is called a pyrheliometer. It consists of a very sensitive black disc which, when exposed to the sun's rays, is heated. The black disc is connected to one end of a thermocouple. As the disc heats a voltage is produced at the other end of the thermocouple. Since the voltage output will vary with the temperature of the disc, the output can be calibrated to indicate Btu per hour per square foot of radiation.

SLIDE #13 (LISTING OF MEANS OF HEAT TRANSFER)

Heat energy moves from place to place in one of three ways:

- by radiation
- by convection, or
- by conduction.

SLIDE #14 (ILLUSTRATION OF CONCEPT OF RADIATION)

Radiation is heat energy given off as rays from a warm body. When the surfaces of an object are warmer than the surrounding environment, the object radiates heat into the environment. The heat from the sun travels to the earth's outer atmosphere by means of radiation.

SLIDE #15 (ILLUSTRATION OF HEAT RADIATION BY FIREPLACE)

Radiation of heat occurs in a cold room with a roaring fireplace. The fire's radiations heat the people in the room. The radiations of their body heat further heats the air in the room.

SLIDE #16 (ILLUSTRATION OF CONCEPT OF CONVECTION)

When air is heated in an open space, it becomes lighter and rises away from the warm object. This creates an air current. Cool air flows in to take the place of the warmed air. The cool air is heated and then rises. When heat is transferred from place to place like this by means of moving air or liquid currents, heat movement is occurring by convection.

SLIDE #17 (ILLUSTRATION OF CONVECTION IN A ROOM WITH A FIREPLACE)

Convection is another means by which a room is heated by a fireplace. Air heated by radiation from the fireplace rises, pushing cooler air down toward the fire.

SLIDE #18 (ILLUSTRATION OF CONCEPT OF CONDUCTION)

When a hot object is placed in contact with a cool object, the cool object becomes warmer. Heat movement from one material to another in contact with it is known as conduction.

SLIDE #19 (ILLUSTRATION OF CONDUCTION FROM WARMED FLOOR)

When we stand on the warm floor in front of the fire, the floor heats our feet by means of conduction.

SLIDE #20 (ILLUSTRATION OF SUN'S RADIATION TO EARTH)

As was mentioned earlier, radiation of energy waves is the means by which the sun transfers its heat energy to earth.

SLIDE #21 (ILLUSTRATION OF CONDUCT OF SOLAR CONSTANT)

If we consider the amount of solar radiation hitting the outer surface of the earth's atmosphere, we find that this amount varies a little, but not much, from point to point. We refer to the amount of heat energy hitting the outer atmosphere as the solar constant.

SLIDE #22 (STATEMENT OF SOLAR CONSTANT'S VALUE)

The solar constant is equal to 429.2 Btu per hour per sq ft. This means that each hr, the sun supplies about 429.2 Btu of heat energy to each square foot of area in the earth's outer atmosphere.

SLIDE #23 (ILLUSTRATION OF CONCEPT OF INSOLATION)

The energy reaching the earth's surface is only about half of that reaching the outer atmosphere. The solar radiation which actually reaches the earth is referred to as insolation. The term insolation should be distinguished from the insulation we use in house wall construction.

SLIDE #24 (ILLUSTRATION OF DIRECT, DIFFUSE, REFLECTED RADIATION)

Insolation may be one of three types of radiation. Direct radiation has traveled in straight parallel rays from the sun. It generates the most heat energy when it hits a surface on earth. Diffuse radiation is radiation whose path has been disrupted by clouds or atmosphere dust. Reflected radiation is radiation which has bounced off other objects on earth, such as other buildings.

SLIDE #25 (ILLUSTRATION OF EFFECTS OF WEATHER ON RADIATION)

One major factor affecting the amount of insolation reaching the earth, and therefore the amount of heat generated on a surface, is the weather. When it is cloudy, the clouds prevent radiation from reaching the earth by absorbing solar radiation or by scattering the solar radiation on its path to the earth.

SLIDE #26 (LISTING OF FACTOR AFFECTING INSOLATION)

The greater the distance through the atmosphere which solar radiation travels, the greater the chance that clouds or other particles in the atmosphere will reduce the radiation reaching earth. Factors such as altitude, season, time of day and latitude affect the distance which solar radiation must travel, and therefore affect the heat energy generated on a surface on earth.

SLIDE #27 (ILLUSTRATION OF EFFECT OF ALTITUDE ON INSOLATION)

The greater the altitude of a surface, the shorter the path of solar radiation through the atmosphere, and the greater the heat energy on that surface. More solar radiation reaches the mountain tops than the streets of the cities.

SLIDE #28 (ILLUSTRATION OF DIRECTNESS OF NOON INSOLATION)

The solar radiation reaching earth is also greater at noon than at other times of day. This is because at noon the sun is more directly overhead. Its radiation travels a more direct and shorter path through the atmosphere.

SLIDE #29 (ILLUSTRATION OF INSOLATION LATER IN DAY)

Later in the day, the sun is lower in the sky, and its radiation travels a longer path through the atmosphere. Less radiation reaches the earth.

SLIDE #30 (ILLUSTRATION OF SEASONAL EFFECTS ON INSOLATION)

For areas in the northern hemisphere, the sun is more directly overhead in the sky in summer than in winter, and there are more daylight hours in summer. So, solar radiation reaching heat is greater in the summer than in winter.

SLIDE #31 (GRAPH OF HOURLY AND SEASONAL VARIATIONS IN INSOLATION)

Time of day and season interact so that the greatest insolation occurs around noon in mid summer, and the least insolation occurs during the winter early in the morning or late in the evening.

SLIDE #32 (ILLUSTRATION OF LATITUDINAL DIFFERENCES IN INSOLATION)

The distance which must be traveled by the sun's rays is also affected by the latitude, or distance from the sun's equator, of the surface reached on earth. The greater the latitude of a surface, the greater the distance through the atmosphere which solar radiation must travel, and the less heat energy generated on earth.

SLIDE #33 (SUMMARY OF FACTORS AFFECTING INSOLATION)

All of these factors must be considered in calculating the amount of heat energy generated on a surface by solar radiation.

SLIDE #34 (ILLUSTRATION OF EFFECT OF SURFACE TILT ON INSOLATION)

In addition, a surface will absorb more energy when it is perpendicular, or right angled, to the path of direct solar radiation. The angle between a surface and the earth's surface is known as the tilt angle, and is important in positioning the solar collectors used to gather energy in solar heating and cooling systems.

SLIDE #35 (PHOTO OF FLAT PLATE COLLECTOR)

The most widely used solar collector in residential solar systems is really a flat surface designed and tilted to absorb and retain maximal solar heat energy.

SLIDE #36 (ILLUSTRATION OF CONCEPT OF AZIMUTH ANGLE)

Absorption of direct rays on a surface can also be increased by facing a surface toward the position of the sun at noon. If this is done, the surface absorbs more of the direct rays available at noon, when the sun is more directly overhead. The term, azimuth angle, is used to refer to the direction of a surface east or west of the sun's position at noon. A surface facing the sun at solar noon has an azimuth angle of zero.

SLIDE #37 (SUMMARY OF FACTORS AFFECTING INSOLATION)

All of these factors must be considered in estimating the amount of solar heat energy that solar collectors can provide to a solar heating system.

SOLAR SYSTEMS: BASIC PRINCIPLES

- a. How would you be able to tell if a solar system were active or passive?

Determine whether the system includes blowers, pumps, or other mechanical devices for transporting heated fluids. Only an active system includes such devices.

- b. Because solar energy is not always available, what two active system components must be included?

auxiliary heating system
storage unit

- c. Describe one example of passive solar heating design.

include south-facing window
include a roof overhang

- d. What is the difference between the way in which flat plate and concentrating collectors gather solar energy? Which are used in residential installations? Why?

A flat plate collector has a large absorber plate to which is transmitted both direct and diffuse radiation. Concentrating collectors gather direct radiation over a large area, and then focus it on a smaller absorber area. Concentrating collectors can produce higher temperatures. However, flat plate collectors are more often used in residences because they produce adequate temperatures, and are less expensive.

- e. List the advantages and disadvantages of air versus liquid systems:

Air Systems

Advantages

1. Lower capital costs.
2. No corrosion, clogging, or anti-freeze solution.
3. Leaks have less severe consequences.

Disadvantages

1. Duct work risers occupy usable floor space.
2. More energy required to move solar energy from collector to storage to use.
3. Installation must be leak tight which is less obvious than with water systems.

Liquid Systems

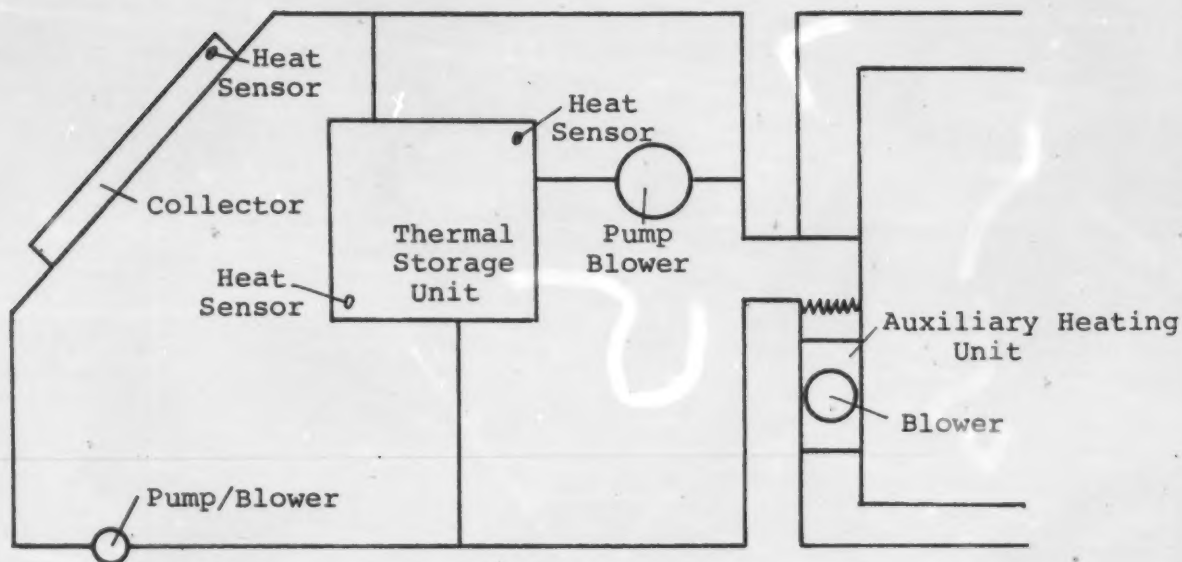
Advantages

1. Water is a cheap and efficient heat transfer and storage medium.
2. Piping uses little floor space.
3. Circulation of water uses less energy for equal heat content.

Disadvantages

1. High initial cost.
2. Corrosion, scale, or freeze can occur causing damage or blockage.
3. Leakage can cause considerable damage to the system and dwelling.

- f. Make a schematic drawing of a solar space heating system. Label each of the major components. Below the drawing, list each major component and its function.

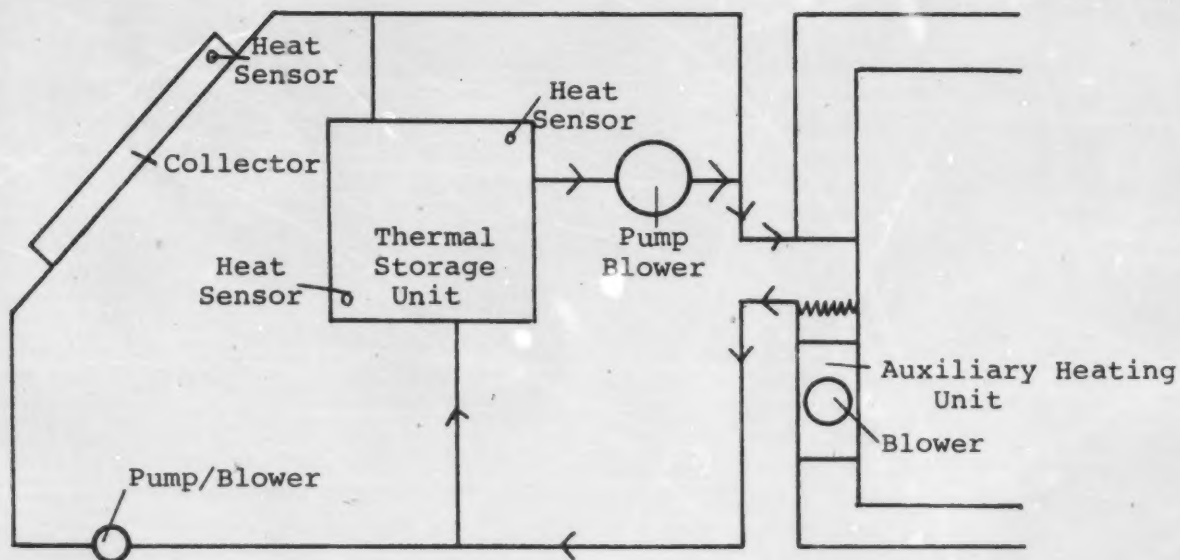


- (1) Solar Collectors - absorbs solar radiation and transmits heat energy to the transfer fluid.
- (2) Thermal Storage Unit - stores heat from the transfer fluid for later use.
- (3) Pump/Blower - circulates the transfer fluid through the system loops
- (4) Auxiliary Heat Unit - provide heat when the solar system cannot meet the demand for heat.
- (5) Heat Sensor - used to measure temperatures at different points in the system for directing system operation.

The system with which the student works should have, minimally, a collector, storage unit, and pump or blower. Ask the student to identify the parts with which s/he's familiar, and their functions. The student should also describe how heat flows when space heating is from collector or storage, or when the collector is heating the storage unit. Ask the student if the system is an air or liquid system, and how s/he can tell this. The student should also identify the type of storage unit.

Inform the student about system components which are different from those described in previous unit activities.

Make a schematic drawing of the major components of a solar space heating system. Indicate the direction in which heat flows when there is space heating from the storage tank.



SOLAR COOLING

- a. Why are heat pumps sometimes included in solar systems?

A heat pump can extract heat from the storage unit at temperatures too low for use in other ways. This heat energy can be used for space or water heating, or can be used to drive the compressor in vapor-compression cooling systems, or to replace the fuel in absorption cooling systems.

- b. In vapor-compression air conditioning systems, where can solar heat be used?

Solar heat can be used to drive the compressor.

- c. In absorption cooling systems, how can solar energy be used?

Solar energy is used by the absorber-generator to heat liquid solution so as to drive the refrigerant vapor out of the solution.

- d. How can Solar Rankine-Cycle engines be used for cooling?

A Solar-Rankine Engine can be used to drive the compressor in a vapor-compression refrigeration cycle.

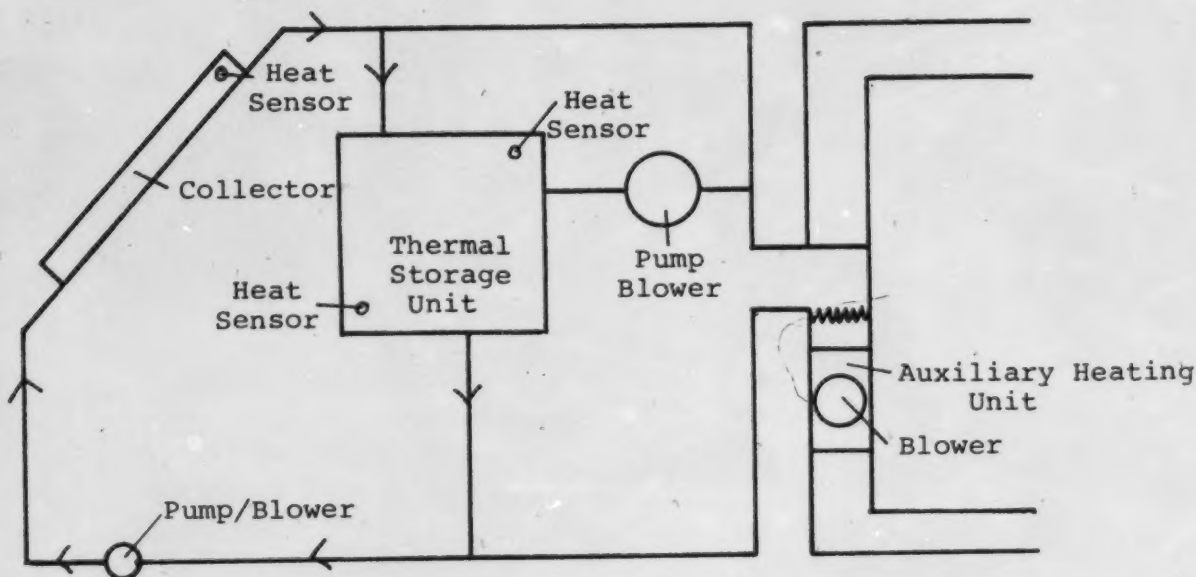
- e. How can a rock storage unit be used to promote cooling?

Circulate cool night air through the rocks to cool them. During the day, hot air from the house is cooled by circulation over the cool rocks.

- f. Describe how a roof pond can be used for solar cooling. Could this same system be used for solar heating? Describe how.

In summer, the water in the roof pond is cooled at night. Then the cool water is circulated through fancoil units to cool the rooms during the day. For winter heating, the roof ponds are exposed to solar radiation during the day. The heated water is circulated through fancoil units to heat air for the rooms.

1. Draw a schematic diagram of the major components of a solar system designed for solar space heating. Label each component. Indicate the direction of heat flow when the storage unit is being heated.



The following parts must be labeled:

collector
storage unit
pump/blower
auxiliary heating unit
sensors

Award 2½ points for each correctly labelled component, and 2½ points for correctly indicating heat flow.

2. Fill in the blanks.

- a. A device called a heat exchanger is used when heat must be transferred from one fluid to another.
- b. In solar heating systems, the unreliability of solar energy makes necessary the inclusion of the following components: thermal storage and auxiliary unit heater.
- c. The kind of collector most frequently used in residential systems is the flat plate collector.
- d. A active solar system uses mechanical means in transporting heat for storage or distribution.
- e. The absorber plate is the component of the collector which converts solar radiation to heat.
- f. Solar systems which use air to transfer heat from the collector are known as air systems.
- g. The back-up component of a solar space heating system is the auxiliary hot water heat.
- h. A rock bed storage unit may be used to store "cold" at night for use during the day.
- i. A heat pump is a refrigerant machine that can extract heat from a source that is at a temperature too low for direct comfort applications.
- j. A flat plate collector collects both direct and diffuse solar radiation.

3. Label each of the following statements as true (T) or false (F).

- a. F Roof overhangs illustrate use of active solar systems design.
- b. T The transparent plate in a collector prevents heat loss by convection.
- c. F Liquid storage is usually used in air systems.
- d. F Usually one collector can satisfy residential heating requirements.
- e. F Pumps are frequently used in passive systems.

- f. F Solar space heating systems cannot be built without including a solar water heating system.
- g. T Fluid returning to the solar collector is usually cooler than fluid leaving the collector.
- h. T Leaks are less damaging in air systems than in water systems.
- i. F Air systems use less energy in transporting heat from collector to storage than do liquid systems.
- j. T Heat pumps can be incorporated in solar heating systems or in solar cooling systems.
- k. F Solar heat can be used to drive the condenser in absorption cooling systems.
- l. F A roof pond which is used for cooling in the summer should be covered at night.

4. List 3 advantages and 3 disadvantages of air systems and of liquid systems. Use the table below to outline your answer.

AIR

Advantages

Disadvantages

- | | |
|--|---|
| 1. Lower capital costs. | 1. Duct work risers occupy usable floor space. |
| 2. No corrosion, clogging, or anti-freeze solutions. | 2. More energy required to move solar energy from collector to storage to use. |
| 3. Leaks have less severe consequences. | 3. Installation must be leak tight which is less obvious than with water systems. |

LIQUID

Advantages

1. Water is a cheap and efficient heat transfer and storage medium.
2. Piping uses little floor space.
3. Circulation of water uses less energy for equal heat content.

Disadvantages

1. High initial cost.
2. Corrosion, scale, or freeze can occur causing damage or blockage.
3. Leakage can cause considerable damage to the system and dwelling.

BASIC COMPONENTS OF RESIDENTIAL
SOLAR INSTALLATIONSSLIDE #1 (VMC Title Slide)

Music up for about five to ten seconds. . .then down under next frame's narration.

SLIDE #2 (Slide set title slide)

The sun radiates enormous amounts of energy. We will now see how this energy can be harnessed for use in residential heating and cooling. Our focus will be on the use of solar energy in homes, rather than in factories or larger buildings.

SLIDE #3 (List of residential uses of solar energy)

In residences, solar energy can be used to serve a variety of functions. Solar energy can be used to heat spaces in homes, to cool spaces in homes, and to heat hot water for domestic use. A solar energy system may serve all, or only one or two of these functions, and this will be reflected in the design of the system. At this point, the technology of solar cooling is both under-developed and expensive, and will not be a major focus of discussion in this presentation.

SLIDE #4 (Illustration of active versus passive design)

One distinction frequently made in describing solar systems is whether they are active or passive systems. Active systems include mechanical means for actively transporting heat energy in the system. Passive systems include no such mechanisms, and depend on natural forces such as gravity or convection to transfer heat, where necessary.

SLIDE # 5 (Photo of direct gain in house)

In passive solar systems, the design or construction of the building often contributes to solar heating. For example, large windows on the south side of a house allow direct solar energy to heat the interior of the house.

SLIDE #6 (Illustration of use of overhang)

Another popular passive solar design is the inclusion of a roof overhang. An overhang blocks out the rays of the higher summer sun, allowing the house to stay cool. The rays of the lower winter sun are not blocked, and contribute to heating.

SLIDE #7 (Definition of passive design)

There are many other examples of passive solar design, which will be discussed later. The common feature is that there is no use of mechanical means for transporting the collected heat energy.

SLIDE #8 (Illustration of active design)

In contrast, active solar systems include mechanisms which actively transfer heat energy to store or distribute it. Pumps or blowers are commonly used mechanisms in active systems.

SLIDE #9 (Drawing of basic solar system)

Here is a schematic drawing of a representative solar space heating system. Note that it is an active system in that it includes liquid pumps and/or air blowers for transporting heat energy. Not all systems will be identical to this one, although most will include the same major components. Let's look at these components.

SLIDE #10 (Solar system with collector highlighted)

The solar collector is the part of the solar system which absorbs solar energy and converts the energy to heat.

SLIDE #11 (Photo of collector)

The type of collector most frequently used in residential systems is the flat plate collector.

SLIDE #12 (Cross-section of collector)

Here is a schematic drawing of a side view of a flat plate collector. The major components can be seen here.

SLIDE #13 (Cross-section of collector with cover highlighted)

The flat transparent cover plates allow heat-producing solar radiation to enter, but not to leave the collector. A flat plate collector may have one or two cover plates.

SLIDE #14 (Collector cross-section with absorber highlighted)

The solar radiation is absorbed by the absorber plate, which then becomes heated. The absorber plate is often painted black or coated with another special surface to increase its absorption of heat.

SLIDE #15 (Drawing of collector fluid movement system)

The heat energy of the absorber plate is transferred to a fluid, either a liquid or air, which is in contact with the absorber plate. This fluid carries the heat to other parts of the solar system, either for storage or for use in heating. Systems which use liquids in the collectors are known as liquid systems. Systems which use air in the collector are known as air systems.

SLIDE #16 (Photo of collectors on roof)

Here is one example of solar collectors already mounted on a roof. Note that many collectors are usually necessary to gather enough heat energy to satisfy residential requirements.

SLIDE #17 (Picture of cloudy day)

One major disadvantage of solar energy is that it is not always available. Solar energy is not available at night, and it may not even be available during the day, if it is very cloudy.

SLIDE #18 (System diagram with storage highlighted)

To deal with this problem, solar systems include a thermal, or heat, storage unit. This storage unit stores heat energy from periods when it is available for use at times when solar energy is unavailable.

SLIDE #19 (Photo of rock storage)

The most widely used storage units contain either pebbles or rocks. . . .

SLIDE #20 (Photo of liquid storage tank)

. . . or contain a liquid, which absorbs heat.

SLIDE #21 (Drawing of air flow through rock storage)

Pebble storage units are generally used in air systems, where the heat transport fluid is air.

SLIDE #22 (Drawing of liquid flow through liquid storage)

Liquid storage units are used in liquid systems, where the heat transport fluid is a liquid.

SLIDE #23 (Drawing of heat exchanger in rock storage)

In solar systems, it is often necessary to transfer heat between materials. In air systems with rock storage, heat is transferred from the air to the rocks in the storage unit.

SLIDE #24 (System drawing with heat exchanger highlighted)

Heat exchange also occurs in liquid systems. A heat exchanger is often used to transfer heat from the liquid in the collectors to a liquid used in the storage unit. Another heat exchanger is used to transfer heat from the liquid in the storage unit to the air used for space heating.

SLIDE #25 (System with auxiliary furnace highlighted)

Solar heating and cooling systems are rarely able to satisfy full heating requirements. To do this very large and expensive collector areas would be necessary. Also, solar radiation would have to be available on a highly reliable basis. Since these requirements are hardly ever met, most solar systems include auxiliary, backup equipment to supplement the solar system.

SLIDE #26 (Photo of furnace)

Where a solar system is being installed in an already built house, the conventional heating system is integrated with the solar system to serve as a backup. In new construction, heat pumps and/or electric resistance heating are often preferred as backup heating units.

SLIDE #27 (List of paths of heat circulation)

Active heating systems must, by definition, include mechanisms for actively circulating the fluid carrying the heat energy. Pumps are used in liquid systems, blowers in air systems.

SLIDE #28 (System with pumps/blowers highlighted)

In air systems, blowers move the heated air. In liquid systems, pumps move the heated liquids.

SLIDE #29 (System with sensors highlighted)

Finally, active solar systems must include control devices which regulate system operation. Control devices are signalled by heat sensors which indicate when heat is needed, and whether the collectors, storage units, or auxiliary unit will provide the heat.

SLIDE #30 (Entire solar system)

We have now briefly examined the major components used in collecting, storing and distributing heat energy in a solar space heating system. Let us now review how the system operates.

SLIDE #31 (List of modes of solar heating)

A solar space heating system has three basic modes of heating: heating spaces from the collectors, heating spaces from the storage unit, and heating the storage unit from the collectors.

SLIDE #32 (System with heating from collectors highlighted)

When heating spaces from the collectors, the heated fluid from the collector transfers its heat to air from the house. The cooled fluid then returns to the collector to be reheated by solar energy.

SLIDE #33 (System with heating from storage highlighted)

When the collectors are unable to provide heat, heat may be transferred from the storage unit to the air from the house.

SLIDE #34 (System with heating storage from collectors highlighted)

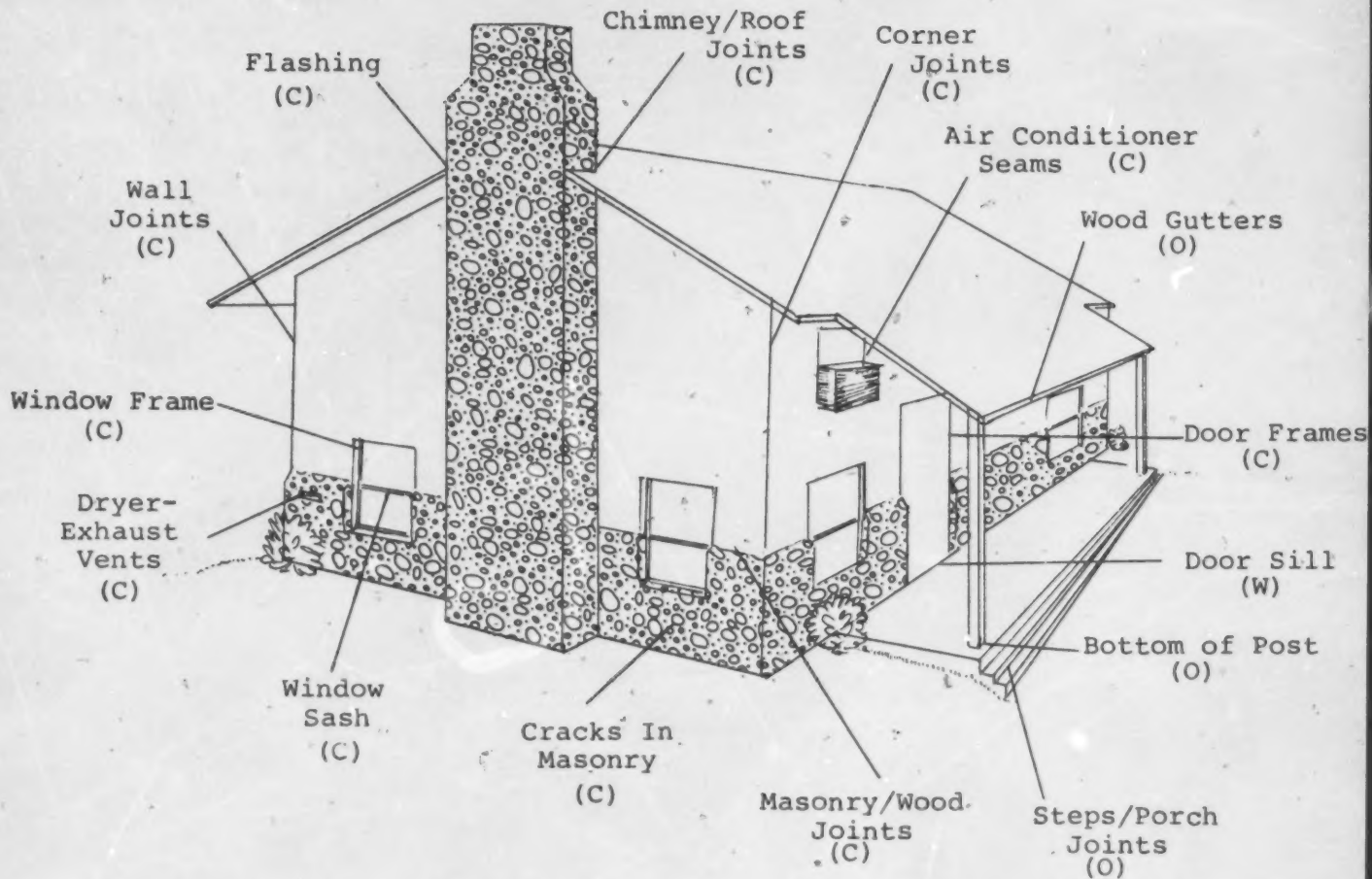
If there is no demand for heat in the house, the heat from the collectors may be stored in the storage unit.

SLIDE #35 (Entire schematic)

Later discussion will detail the components of the system and their operation.

WEATHERSTRIPPING AND CAULKING

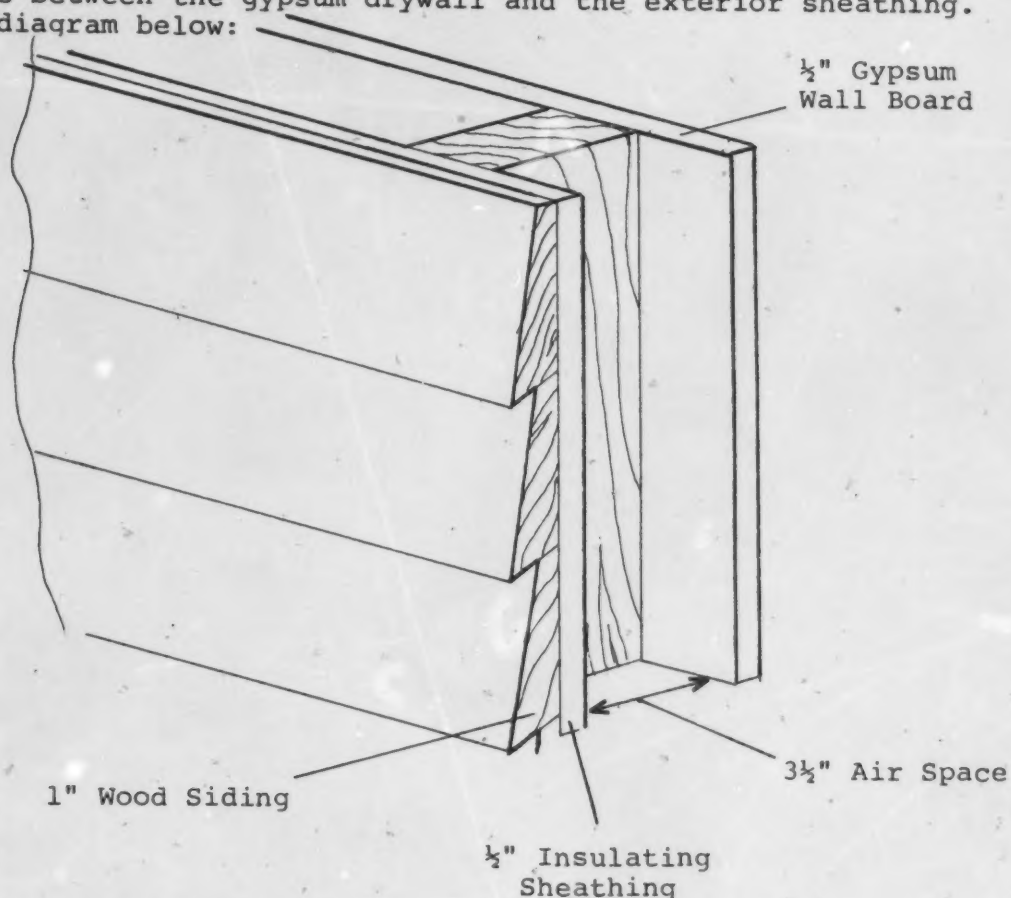
1. For the following diagram, place a "C" at each location where caulking may be necessary. Place a "W" where weatherstripping is needed. Place an "O" where neither is needed.



2. The purpose of weatherstripping and caulking is to
reduce air infiltration
3. Use a hair dryer and check the exterior doors in your residence for the effectiveness of existing weatherstripping. Does any of this weatherstripping need replacement?
4. Check the prices at your local supplier for the types of weatherstripping listed in Table SB-1-3.2 on Information Sheet SB-1-3. Enter the price you locate on that table. What are the two best choices in your area? Why did you select these two, rather than the others on the list?
5. Repeat question (4) for caulking listed in Table SB-1-3.1.

INSULATION

1. Suppose an existing house has exterior walls constructed of common brick, on a standard 2" x 4" stud wall, with $\frac{1}{2}$ " of drywall in the interior. Such construction leaves a $3\frac{1}{2}$ " air space between the gypsum drywall and the exterior sheathing. See diagram below:



Such a wall may have an R value of about 4.0. Using Table SB-1-4.1 in Information Sheet SB-1-4 (Insulation), determine the highest R_{TOTAL} that can be attained by filling the $3\frac{1}{2}$ " air space with insulation.

Blown polyurethane would add about $6.5 \times 3.5 = 22.5$ R -value to the wall. Loose-fill fiberglass would add about $3.5 \times 3.5 = 12.5$ to the wall. The actual increase would be slightly less than that given, because the air space has an R -value of 1.0.

2. Visit a local supplier and fill in the "Cost" column in Table SB-1-4.1 in Information Sheet SB-1-4. Verify the R-values in the table for the brands available at this supplier.

3. What is the purpose of a vapor barrier?

The vapor barrier prevents condensation of water into insulation.

4. Which side of the insulation should the vapor barrier be?

On the side toward the heated space.

5. In the following list, place a letter "I" beside locations which should be insulated.

- Interior walls
- (I) Exterior walls
- Ceilings exposed to heated rooms
- (I) Ceilings exposed to unheated attics
- (I) Living area ceiling directly covered by roofs
- (I) Floors exposed to unheated areas
- All hardwood floors
- (I) Crawl space walls
- (I) Band joist
- (I) Basement walls

6. Use the Table SB-1-4.2, and determine how much insulation should be used in floors and ceilings in this area.

1. What is air infiltration?

Movement of air into the house.

2. Name four ways to reduce air infiltration.

See Information Sheet SB-1-1 for list of seven.

3. R-value measures resistance to heat flow.

4. The reason 2" x 6" studs are used in the Arkansas Plan home is:

to permit 6" of insulation rather than 4". When fiber-glass is used, this brings the wall to standard of R-18.

5. What is the difference between weatherstripping and caulking?

Caulking seals cracks; weatherstripping seals the joints where doors and windows close.

6. If a material has an R-value of 3, per inch of thickness, how many inches of the material are needed to give an R-value of 18?

6"

7. What R-value should walls and ceilings in your area have?

See Table SB-1-4.2. Atlanta has about 2900 degree days.

8. Should interior walls and ceilings under heated spaces be insulated?

No

9. What side should a vapor barrier face? heated side

10. Describe ideal placement of windows from an energy efficiency standpoint.

Little window area on north and west sides; most window area on the south side.

1. Air leakage in a house is called infiltration.

2. Name four locations for air leakage in most houses.

soleplate, exterior wall outlets, duct system, windows, doors, range vent, fireplace, sliding glass door, etc.
See Table SB-1-1.1.

3. Name remedies for leaks at these locations.

See Information Sheet SB-1-1. In general, caulking, weatherstripping, taping seams, or elimination of certain features are to be recommended.

4. What type framing does Arkansas Plan construction use?

2" x 6" studs on 24" centers

5. Why does Arkansas Plan framing help energy efficiency?

In order to allow for a 6" thickness of fiberglass insulation, which gives R-19 protection in the walls.

6. There is less lumber used in Arkansas Plan construction.
True or False?

True

7. Plywood headers over windows and doors are required for structural strength in Arkansas Plan Houses. True or False?

True

8. It is not recommended that concrete slab floors be insulated.
True or False?

False

9. Duct work should be placed, wherever possible, within insulated living space. True or False?

True

10. Caulking and weatherstripping act to: (Circle one.)

- a) Increase the R-value of walls
- b) Reduce air exchange
- c) Keep out insects
- d) Reduce energy use
- e) All of the above.

(e) is correct.

11. Weatherstripping is used where: (Circle one.)
- a) Doors and windows open and close (a) is correct.
 - b) Cracks exist around door frames
 - c) Soffit vents
 - d) Caulking is too noticeable.
12. Most brands of weatherstripping are pretty much the same, in terms of durability, cost, and ease of installation. True or False? False
13. Most brands of caulking are the same, in terms of durability. True or False? False
14. Weatherstripping and caulking should be done: (Circle one.)
- a) After all other energy-saving measures are complete
 - b) Frequently
 - c) As an essential first step. (c) is correct.
15. Name three types of caulking and report their advantages, disadvantages, and cost.

See Table SB-1-3.1 from Information Sheet SB-1-3.

16. Name three types of weatherstripping and report their advantages, disadvantages, and cost.

See Table SB-1-3.2 from Information Sheet SB-1-3.

17. R-value is resistance to heat flow.
18. Cellulose fiber is a naturally fire-resistant insulation. True or False? False, it must be treated.
19. Name two problems with urea formaldehyde insulation.
It's not fire-resistant and it may shrink up to 3%.

20. The highest R-value per inch is given by polyurethane.
21. R-values recommended for your area for the following locations are: (See Table SB-1-4.2 from Information Sheet SB-1-4.)
- a) Ceilings under unheated space R22, R30
 - b) Exterior walls R13, R13
 - c) Floors over unheated space R13, R19
22. What is the purpose of a vapor barrier? Atlanta has 2918 degree days. Answers are for Atlanta.)

To prevent moisture in the air from condensing in the insulation.

23. Are all vapor barriers fire-resistant? No

Which side should the vapor barrier face? heated side

24. The air space between studs in an uninsulated wall has an insulating value that is:

- a) higher than,
 - b) lower than,
 - c) about equal to,
- (b) is correct

insulating sheathing.

25. Here is an example of an R-value_{TOTAL} calculation. Check each step for correctness.

Example: The wall is made of:

1" exterior siding	R-value of .8, per inch
$\frac{1}{2}$ " insulating sheathing	R-value of 1.0, per inch
$3\frac{1}{2}$ " air space	R-value of .33, per inch
$\frac{1}{2}$ " gypsum wallboard	R-value of 1.0, per inch

Calculation: The R_{TOTAL} for the wall is figured in five steps.

Step One.	1" x .8 = .8	Correct?	<u>Yes</u>
Step Two.	$\frac{1}{2}$ " x 1.0 = .5	Correct?	<u>Yes</u>
Step Three.	$3\frac{1}{2}$ " x .33 = .99	Correct?	<u>Yes</u>
Step Four.	1" x 1.0 = 1.0	Correct?	<u>No</u>
Step Five.	Add up all the R-values to get R _{TOTAL} for the wall.	Correct?	<u>Yes</u>

26. High gloss enamel can be a good vapor barrier. True or False? True

27. The best orientation for windows is south.

28. Explain why you answered #27 as you did.

More winter sun shines in south windows than summer. North windows lose heat during winter; west windows gain too much heat in summer.

29. a) Jalousie, crank-type windows are better than casement windows for energy efficiency. True or False?

False

b) Wood windows are more energy efficient than metal windows. True or False?

True

30. From what you have studied so far in the course on solar energy, why should a solar heating technician expert know about energy efficiency?

Solar systems, active or passive, are more dependent on the outside weather conditions than other HVAC systems. Therefore, the house using solar systems must do the best possible job of resisting extremes of outside temperature.

To aid the student in carrying out this exercise, you will need to:

1. Identify a site for the energy efficiency audit. You may wish to utilize a site near the campus so that you can independently verify the accuracy of the student's observations. You may also wish to allow the student to audit his own or a friend's house. An ideal set-up would be a model house on campus, "wired" for known defects. The exercise is important, however, even if done on the student's own dwelling, since it forces him/her to use all the information gained in the unit, both to make up the Survey, and to make the audit. Communication of the results is also an important skill.
2. Review with the student the Energy Efficiency Survey created by the student. The survey should be in check-list form, and include items from the following categories: Weatherstripping, Caulking, Insulation, Doors and Windows, and Tight Construction. Items within each category should reflect the content of the readings for this unit.
3. Review with the student the completed Survey Form and the written recommendations, before the student returns to meet with the house occupant. Check for accuracy in the cost estimates, as well as consistency with good practice, as outlined in the unit.
4. Assign a grade to the student (up to a total of 70 points) on the Survey Form, his recommendations, and on the tape of his verbal presentation to the customer. The verbal presentation should be accurate and easy to understand, well-organized and phrased in non-technical language. When technical terms are used, they should be explained.

1. The difference between passive, hybrid, and active systems depends on whether thermal energy flow is natural or forced. Label the following rows (a,b,c, & d) with the correct word-- active, passive, or hybrid.

(a) <u>Passive</u> System	Thermal Energy	Flows
	Natural	Forced
Collector to Storage	X	
Storage to Space	X	
(b) <u>Hybrid</u> System	Natural	Forced
Collector to Storage	X	
Storage to Space		X
(c) <u>Hybrid</u> System	Natural	Forced
Collector to Storage		X
Storage to Space	X	
(d) <u>Active</u> System	Natural	Forced
Collector to Storage		X
Storage to Space		X

2. Looking at the direct gain diagram on Information Sheet SB-2-1, answer the following questions.
 - (a) Which way should the glass in a direct gain system be oriented? South
 - (b) How can excess heat gain in the summer be prevented?
roof overhang, deciduous trees
 - (c) How can heat loss at night be reduced, in this direct gain system?
insulated draperies, removable insulating shutters
 - (d) What is one disadvantage to use of direct gain as the only means to heat a space?
wide temperature swings through the day, glare, fading of fabrics.
3. Looking at the indirect gain diagram: Thermal Storage Wall from Information Sheet SB-2-1, answer the following questions:
 - (a) Why are there openings in the top and bottom of the thermal storage wall? The sun heats the air between the wall and the glass or plastic. Heated air rises and enters the room through the top vent, pulling cooler room air from the room into the space to be heated.
 - (b) What could be done to prevent unwanted heat loss at night? Manual or automatic dampers may be installed at the vent openings, insulated shutters may be added to the outside.
 - (c) Can you think of three ways to reduce summer heat gain in this system? deep roof overhangs, deciduous trees, and exhaust vents at top of glazed area. Another opening in the living space from a shaded or cooler area will allow cross-ventilation.
4. Thermal storage roof ponds can provide both heating and cooling. The diagram on Information Sheet SB-2-1 suggests why. Answer the following questions:
 - (a) The dotted material in the sketch is moveable insulation. Why is it essential? To prevent heat gain in summer days and heat loss on winter nights.
 - (b) What can be done to prevent loss of water by evaporation? Store the water in dark-colored plastic bags.

- (c) Is energy transfer in this system more by radiation or by convection?

Radiation.

5. The solar greenhouse is one passive approach that can be added to existing buildings.

- (a) Where might heat be stored in this design?

floors, walls, pools of water

- (b) Can you think of some ways to control heat flow in solar greenhouse or "sunspace" type building?

Adjustable vents, moveable wall panels, shading, moveable insulation

- (c) The convective loop water heater and the thermosiphoning air collector operate on the same principles. Looking at the diagrams, tell what they have in common.

Warm fluid tends to rise, and cool fluid takes its place. In these collectors, a fluid (either liquid or air) flows into contact with a solar absorbing surface. The warm fluid rises to space or storage, often located above the absorber, and cooler fluid is drawn from the space or storage to replace it.

- (d) From what you've seen so far, what are the main advantages of passive solar design?

Independence from high cost or scarce energy supplies.

"Instructor's Materials"

General Design:

Isolated Gain

Design Type:

Sunspace

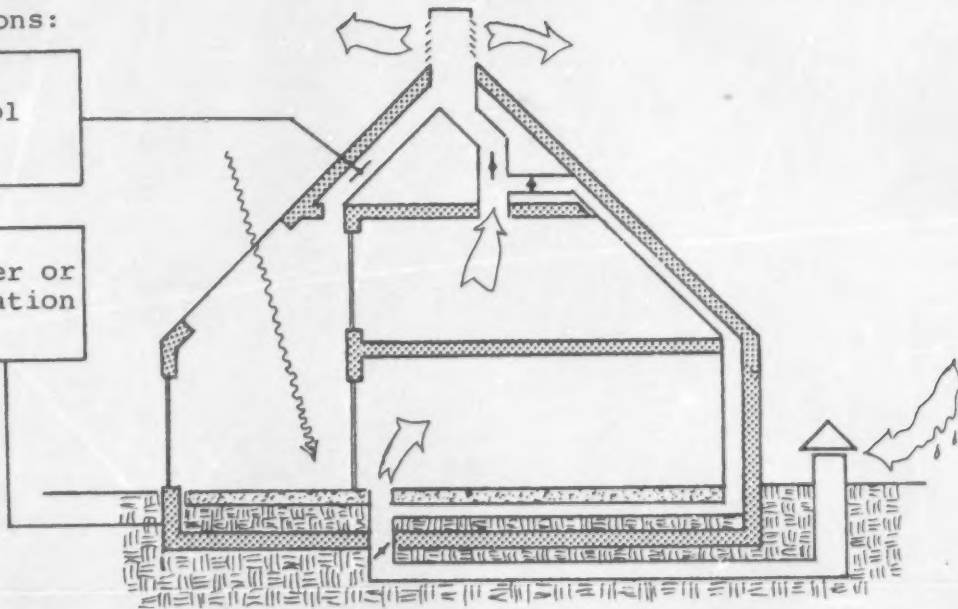
Heat Flow Type:

Summer Day

Functions:

Control

Heat
Barrier or
Insulation



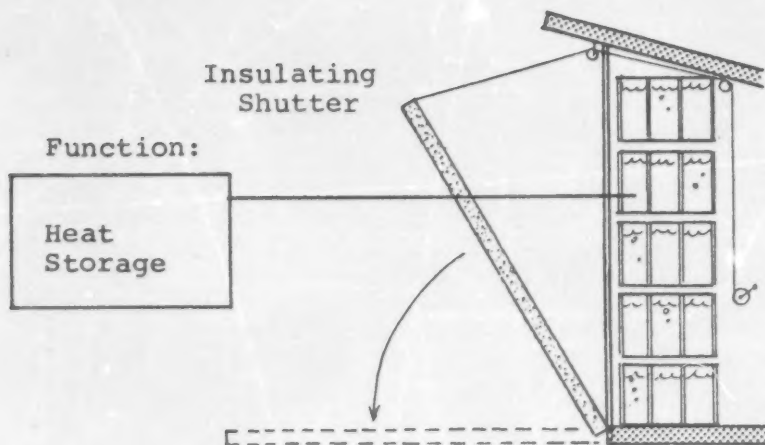
"Instructor's Materials"

General Design:

Indirect Gain

Design Type:

Water Trombe Wall



"Instructor's Materials"

General Design:

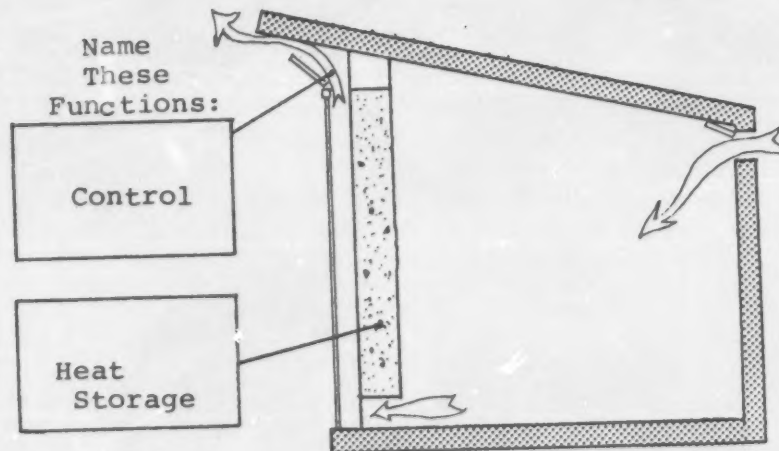
Indirect Gain

Design Type:

Mass Trombe

Type of Heat Flow:

Summer Day



"Instructor's Materials"

General Design

Isolated Gain

Design Type:

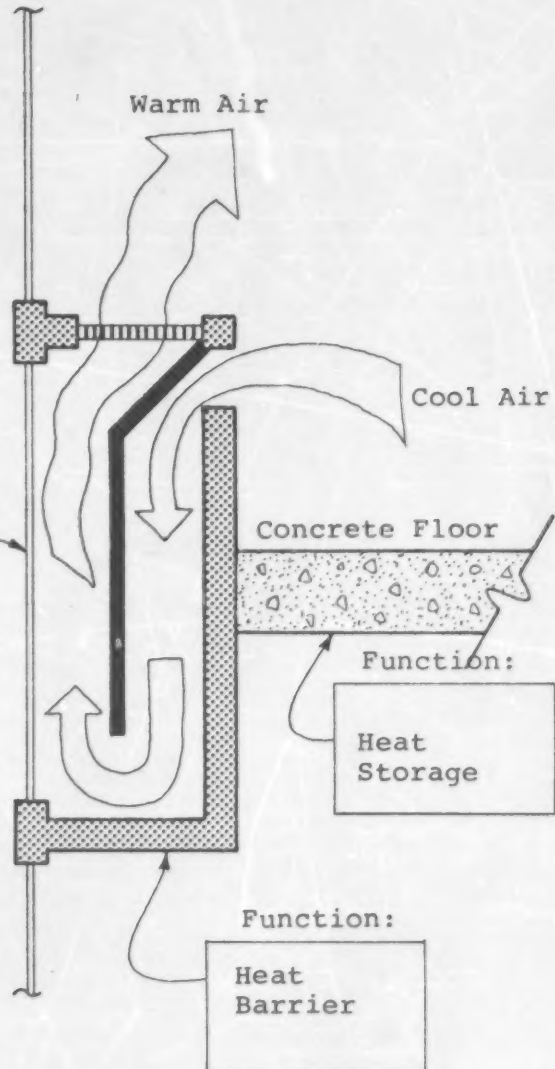
Air Thermosiphon

Type of Heat Flow:

Winter Day

Function:

Solar
Energy
Trap



"Instructor's Materials"

General Design:

Isolated Gain

Design Type:

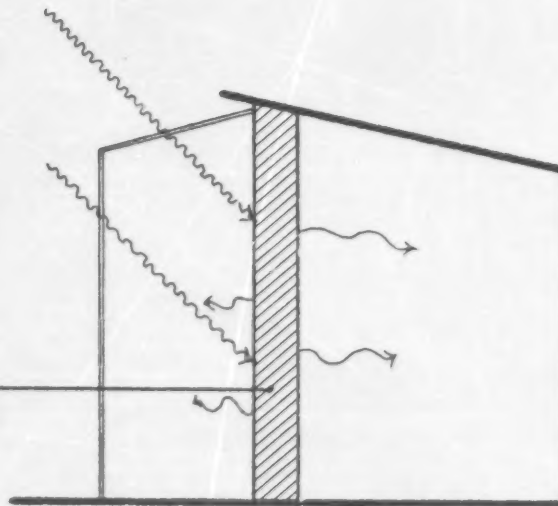
Sunspace or
Solar Greenhouse

Type of Heat Flow:

Winter Day

Function:

Heat
Storage



"Instructor's Materials"

General Design:

Indirect Gain

Design Type:

Thermosiphon

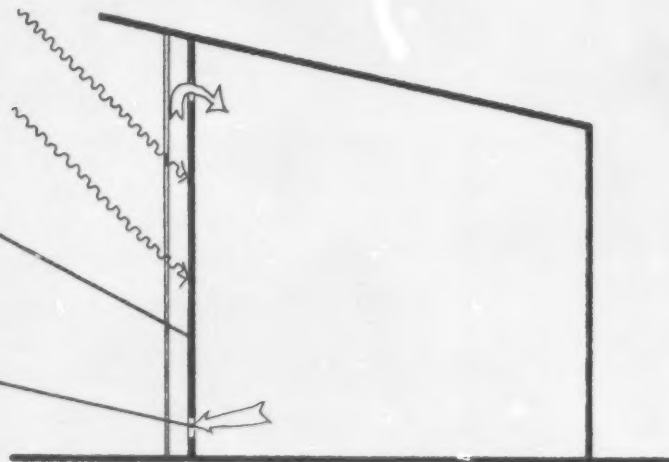
Type of Heat Flow:

Winter Day

Name These
Functions:

Heat
Barrier

Control



"Instructor's Materials"

General Design(s):

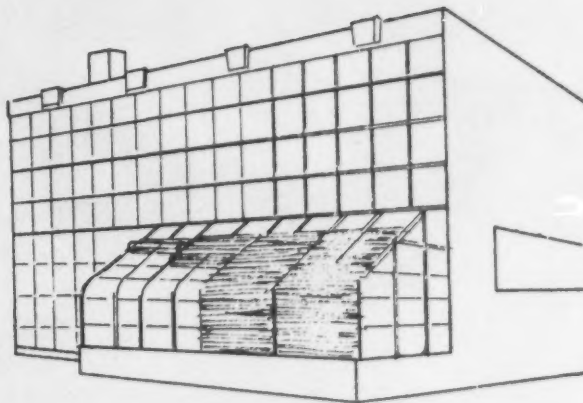
Indirect and
Isolated Gain

Design Type:

Mass Trombe and
Sunspace

Type of Heat Flow:

Winter Day

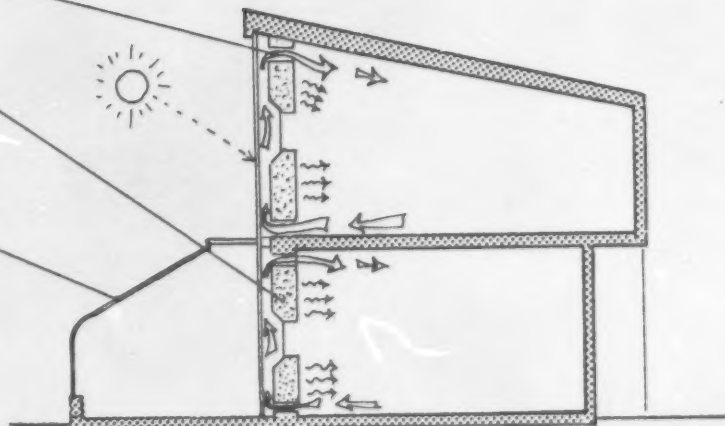


Name These Functions:

Control

Heat Storage

Solar Energy Trap



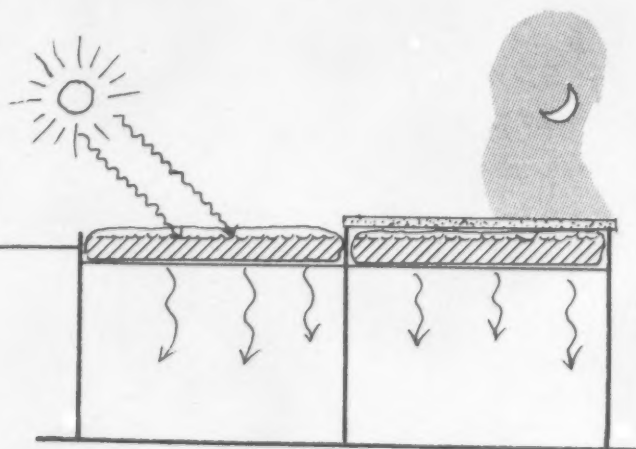
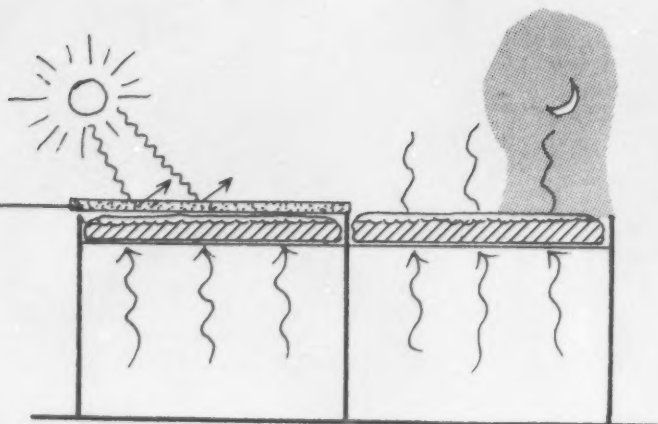
Heat Flow Type:

Summer Day
and Night

Name
These
Functions:

Heat
Barrier

Heat
Storage



Heat Flow Type:

Winter Day and
Night

"Instructor's Materials:

General Design(s):

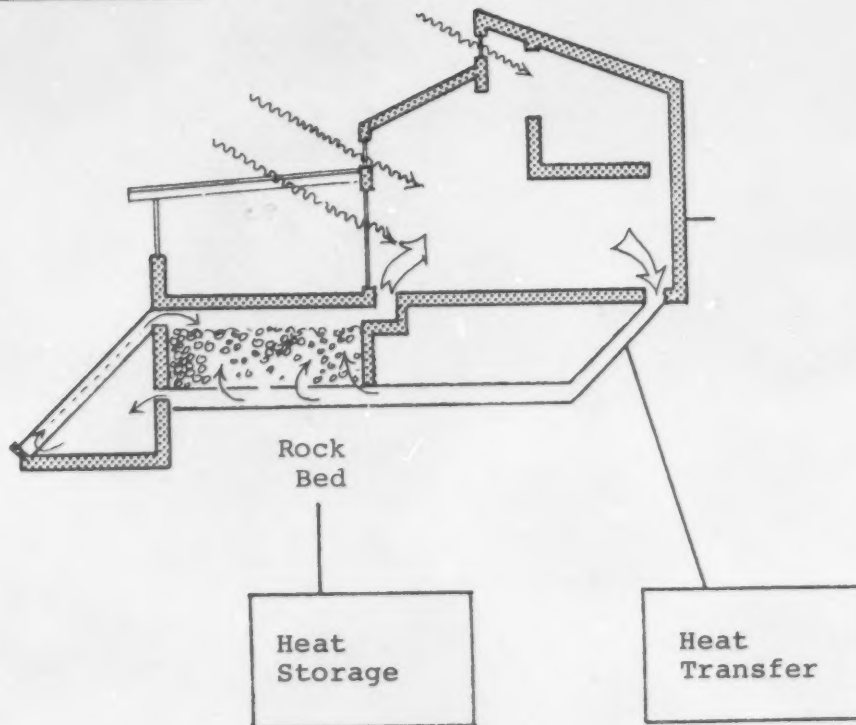
Direct and
Isolated Gain

Design Type(s):

Direct Gain
Sunspace Thermosiphon

Type of Heat Flow:

Winter Day



Name These Functions:

Define the following terms:

1. Passive solar system.

A system of heating and/or cooling which utilizes the structure of the building and the natural flow patterns of thermal energy to provide heat and/or cooling.

2. Hybrid solar system.

A passive solar system which is combined with additional means of heating and/or cooling.

3. Direct gain.

A system which allows the sun's energy to heat the living space directly.

4. Indirect gain.

A system which allows the sun's energy to heat a storage mass such as concrete or water, before the heat is transferred to living space.

5. Isolated gain.

A system in which the means of collection and/or storage is separate from the structure of the building.

6. Name two examples of Indirect Gain systems.

Mass Trombe Wall, Water Trombe Wall, Roof Pond.

7. Name two examples of Isolated Gain systems.

Solar Greenhouses, Thermosiphoning Air Collectors,
Thermosiphon Water Heaters

8. Name one way to avoid wide temperature swings in a Direct Gain heating system.

Use a thermal mass for heat storage.

9. Single glazing on a south wall in Atlanta provides a net energy gain of 9 Btu/ft²/hr.

10. Double glazing on a south wall in Atlanta provides a net gain of 18.8 Btu/ft²/hr.

11. The best orientation for the long axis of a house is
South or slightly east of south

12. Name several controls for passive heating/cooling systems.

Dampers, roof overhangs, removeable insulation, deciduous trees planted on south and west sides.

13. In a Mass Trombe Wall, what is the function of the vent at the bottom?

To allow cool room air to flow into the space between the mass wall and the glazing.

14. In what two ways is heat provided by the Mass Trombe Wall?
Radiation from the mass; convection through vents.
15. Name four main aspects of the design of a house that affects the amount of solar energy it receives.
- (a) its shape
 - (b) its orientation
 - (c) its window arrangement
 - (d) its shading patterns.
16. Name two ways to affect the amount of heat a house stores.
- (a) its construction materials
 - (b) its color
17. True or False: Most materials which are good heat storage means are rather poor insulators.
True
18. True or False: For each degree Fahrenheit rise in temperature, a cubic foot of water stores more heat than a cubic foot of concrete.
True
19. During the summer, a building will normally gain the most heat on its east & west walls.
During the winter on its south walls.
20. To take advantage of the heat provided by south facing windows, about how much heat capacity should be provided for storage for each square foot of window area:
- (a) When the mass is exposed to the sun.
30 Btu/°F
 - (b) When the mass is not exposed directly to the sun.
120 Btu/°F

1. Suppose a house loses 300 Btu/hr/°F. It is built on a concrete slab 20' x 20' x 4" thick. If the concrete slab is warmed to 75° on a winter day, and the house air is 65°, if the difference (on the average) between inside air and outside during the night is 30°, how many hours can the slab heat the house to 65° before auxiliary heat is required?

The slab has $(20 \times 20 \times \frac{1}{3}) = 200$ cubic ft of concrete

Concrete could give up $(200 \times 31.7 \text{ Btu} \times 10) \text{ Btu} = 63,400 \text{ Btu}$

The house loses $(300 \text{ Btu} \times 30) \text{ Btu/hr} = 9,000 \text{ Btu/hr}$

$63,400 \div 9,000 = 7.4$ hrs of heat without auxiliary heating.

2. Suppose you are the heating and air conditioning contractor for a group of speculative homes that are to be built. Part of the land involved is a long east-west ridge sloping down on the south side. What recommendations can you make about siting the homes to be built along that ridge?

Place the houses facing the south slope; have the north wall dug into the hill, rather than on the surface only.

3. Use of passive design principles in new construction can reduce heating and cooling loads on active systems by 50 percent or more. What three reasons can you think of that will prevent greater use of these principles?

Higher initial cost for materials, lack of understanding of these principles on the part of the general public, difficulties in adapting older homes to these principles, public expectations of uniform temperatures in homes, reduced percent of profit for heating and air conditioning contractors.

4. What ways can you think of to encourage the greater use of passive design principles in building construction?

Education of tradespeople, education of general public, greater involvement of knowledgeable HVAC people in design phases, packaged passive units, such as thermosiphoning walls.

1. Why do most picture windows not contribute to house heating?

Because there is usually no thermal mass available to store heat gained.

2. Name three commonly used types of thermal storage materials.

Concrete, brick, sand-filled concrete, water.

3. Name several controls for direct gain systems.

Overhang for south glazing, exhausts, vents, movable insulation panels.

4. Why are overhangs not good controls for east or west windows?

Because east and west windows are faced with low sun angles.

5. How can convection be used in the Mass Trombe Wall to provide summer cooling? That is, what controls must be available to make this possible?

Exhaust vents at top of glazing, openings in room opposite the glazing, damper at top of mass.

6. Using the Survey text, select one house from the Indirect Gain type, and one from Direct Gain type, which you believe would be both "saleable" and effective as passive solar systems in your area. Tell why you chose these, from the standpoint of style, climatic data, building materials, size, etc. (Each of the above criteria should be addressed for an adequate answer.)

7. Name desirable controls for a Water Trombe Wall.

Insulation between water wall and living space, high and low vents with dampers, moveable exterior insulation.

1. What climate will permit a roof pond system to be used for summer cooling?

Where large differences between day and night temperatures exist.

2. Why would a "roof pond" sometimes be located in an attic?

In latitudes with lower winter sun angles and some snow build-up. A glazed attic enclosure may be preferred.

3. Name three examples of a "sunspace."

Atrium, sun porch, greenhouse, sunroom.

4. Why is thermal mass necessary in a "Sunspace?"

To retain heat for non-sunshine hours.

5. Name essential controls for "Sunspace" type passive systems.

Shading, moveable insulation, vents.

6. What is a convective loop?

Air or liquid is moved across a heated surface by the natural tendency of warm air or liquid to rise; cooler air drops to the bottom.

UNIT SB-2
UNIT TEST PART ONE
10 PERCENT

Grade the student's best tape made for Job Sheet SB-2-1.

Assign it from one to ten points on: clarity

accuracy

sales value.

1. A heating system for a house in which the principal energy flows are due to natural convection and radiation is called passive solar

A system in which some of the energy flows are by natural convection and radiation and some are forced is called a hybrid system.

3. The primary elements in a passive solar system are:
Collection of solar energy or glazing on south walls,
proper orientation of the house shading
provision of thermal mass, good insulation

True or False:

4. Single glazing on a south wall provides a net heat gain anywhere in the U. S. True

Use of passive solar principles means that more than 50 percent of heating needs can be provided by the sun.

True

Good insulation is also good thermal mass. False

5. If a house has 100 square feet of south-facing window, how much thermal capacity should be available:

(a) exposed to the sun 3,000 Btu/°F

(b) not exposed to the sun 12,000 Btu/°F

6. The diagrams below show six major passive design types. Name each.

Direct Gain; Indirect Gain: Thermal Storage Wall or Trombe Wall; Indirect Gain: Roof Pond; Isolated Gain: Solar Greenhouse; Isolated Gain: Convective Loop or Thermosiphoning Water Heater; Isolated Gain: Thermosiphoning or Convective Loop Air Collector.

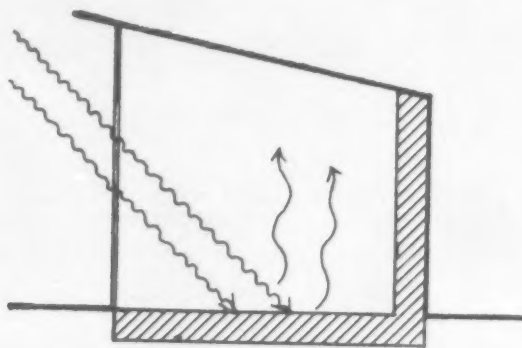


Figure 1. Direct Gain

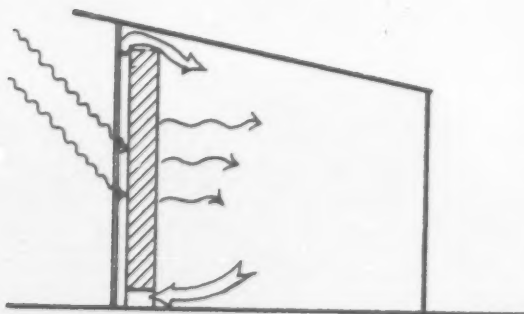
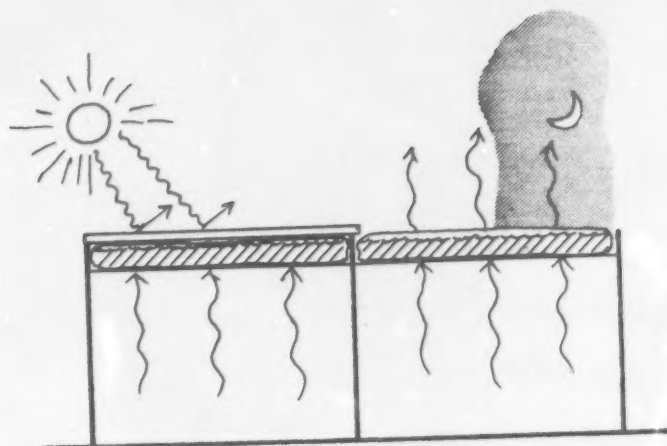
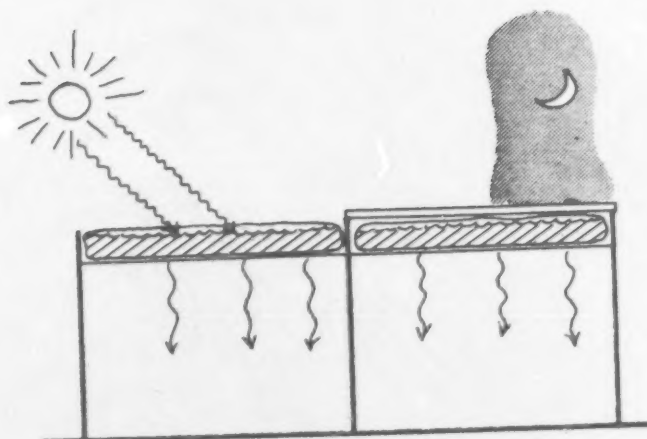


Figure 2. Indirect Gain: Thermal Storage Wall



Summer Cooling



Winter Heating

Figure 3. Indirect Gain: Thermal Storage Roofs: Summer & Winter Operation

Source: U. S. Department of Energy, D.O.E./CS-0011, UC-59a, b, c; August, 1978.

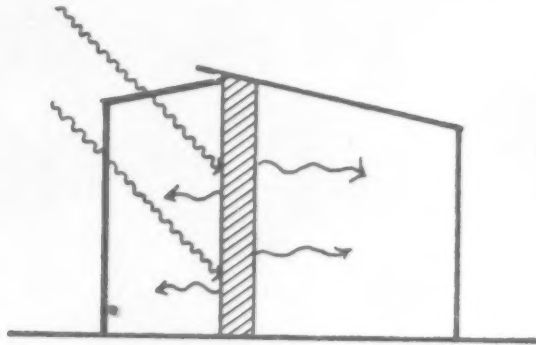


Figure 4. Isolated Gain: Solar Greenhouse

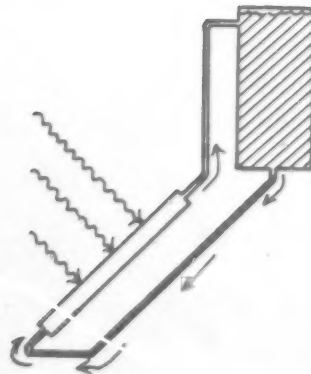


Figure 5. Isolated Gain: Convective Loop:
Water Heating

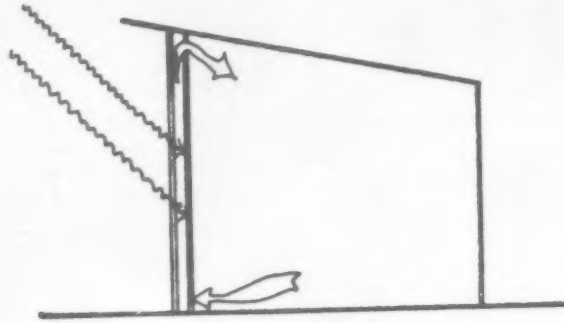


Figure 6. Isolated Gain: A Thermosiphoning
Air Collector

13. Suppose you have a Trombe Wall used for winter heating. What can you do to prevent overheating in the summer?

You may have moveable insulation closed in the daytime and open at night; or you may have high vents in the glazing, and a vent on the opposite side of the living area to draw hot air out. The top vent in the Trombe wall must be closed for this to be effective.

14. How does a roof pond work for heating and cooling?

The water bags store heat during a sunny day; insulation is closed about them at night, heat radiates to people below. In summer, the bags are insulated from the sky in the daytime, absorbing heat from rooms below. At night, the bags are uncovered, radiating heat to the cooler night air.

15. Name three common building materials which are effective as heat storage materials.

Concrete, asphalt white oak, brick, gypsum sand, white pine fir

Rank order the three you named with respect to their heat capacities:

(See above for order)

Is water better or worse than the best above?

Better

16. Which of these is most economical for use in your area, considering material and labor costs?

17. Name three commonly used controls for passive systems.

Beadwall, Skylids, dampers, overhangs, moveable insulation, deciduous trees.

18. Define: convective loop/thermosiphon:

A pattern of heat from which takes advantage of the tendency for warm air or water to rise, pulling cooler air or water with it past a heat absorber.

19. Name principle disadvantages to use of passive solar heating/cooling in your area.

Higher first cost, and
novelty of the ideas) affect saleability
need for education)

20. Name principle advantages to use of passive solar heating/cooling in your areas.

Savings in fossil fuel use
greater independence
non-polluting method of heating

PASSIVE SOLAR APPROACHES:
HOW WELL DO THEY WORK?

SLIDE #1 (Title: "PaSSIVE SOLAR APPROACHES: HOW WELL DO THEY WORK?)

Many people believe the best approach to solar heating and cooling is passive--letting nature do the work to keep a house comfortable. Future homes may be built so as to heat and cool themselves nearly independently of outside energy sources. Let's look at the heating and cooling performance of some houses already built with this idea in mind.

SLIDE #2 (DIAGRAM OF ENERGY FLOW IN DIRECT GAIN SYSTEM)

The most common passive solar approach is direct gain. Simply diagrammed, the energy flow is from sun to living space to storage mass. Using double glazed glass in south facing windows provides a net heat gain anywhere in the U. S. Using construction materials that can store heat lets the walls and floor soak up heat to heat the house. Good materials for heat storage include concrete, brick, sand, and ceramics, as well as water or other liquids. One problem with direct gain systems is that if insufficient heat storage is present, the air will overheat during sunny parts of the day, and be too cool otherwise.

SLIDE #3 (SAN FRANCISCO CLIMATIC DATA)

This is the climate data, and the data on the performance of the first direct gain house built in Northern California. The house

has 1150 square feet. It is 95 percent heated by 375 square feet of double glazed, 70° slope, south facing windows. The next slide shows this house.

SLIDE #4 (DAVID WRIGHT HOUSE SKETCH)

The house is built of stone masonry and frame, and is sunk 4 feet into the ground on 3 sides.

SLIDE #5 (DAVID WRIGHT RESIDENCE: DIAGRAM)

This diagram shows how an insulating space blanket curtain is used over the glass area to hold heat in at night and shade during the summer. Cooling is accomplished by this design as well. The south glazed wall and the space blanket curtain provide a thermosiphoning air circulation vented to the outside to cool the southern face. Deep overhangs are used to prevent unwanted summer heat gain.

SLIDE #6 (KNOXVILLE CLIMATE DATA)

Passive approaches work well in the southeast. At University of Tenn. in Knoxville, the sun provides 85% of the heating needs of a 2 story, 3 bedroom home.

SLIDE #7 (U.T. SOLAR HOUSE: DIAGRAM)

In the U.T. Solarhouse, solar radiation is received via 170 sq ft of vertical double glazed windows. It strikes 544 sq ft of

carpeted 4 in. thick concrete floor, which serves to store the heat gathered on sunny days, and to prevent overheating of the air.

SLIDE #8 (INDIRECT GAIN: DIAGRAM OF ENERGY FLOWS)

In the INDIRECT GAIN passive solar building type, a storage mass collects and stores heat directly from the sun, and then transfer heat to the living space. One main type of indirect gain system is the mass trombe wall, named after the Frenchman who first designed it.

SLIDE #9 (FAYETTEVILLE, ARKANSAS, CLIMATIC DATA)

A 2000 sq ft house in Fayetteville, Arkansas is located just south of a wooded hilltop. The hybrid passive system provides 60-75 percent of the heating requirements.

SLIDE #10 (DELAP HOUSE: DIAGRAM)

In the diagram you see, the south wall includes 860 sq ft of double glazed windows, which transmit heat directly to the living space, and to a 12" thick black-painted masonry wall. The air space between the window wall and the masonry wall heats up by convection, and when it is overheated, a thermo-switched fan draws the air into the enlarged house return air duct to a rock bed storage located below ground. Since this energy flow is forced, the system is called hybrid.

SLIDE #11 (WATER TROMBE WALL: DIAGRAM)

The Water Trombe Wall involves the same principles as the Mass Trombe Wall, but uses water in some type of storage tank in place of masonry or other materials. If the water is stored in large volumes, greater and longer term heat storage capacity is provided. Smaller containers provide more heat exchange surfaces and thus faster distribution of heat.

SLIDE #12 (CHICO, CALIFORNIA CLIMATIC DATA)

In California, a house with water cylinder storage is 90 percent passive heated. It has 1645 sq ft of space and is wood frame 2 x 6 construction, allowing for 5" of insulation in the walls.

SLIDE #13 (DICKENSON HOUSE: SKETCH OF SUMMER NIGHT OPERATION)

South glazing and a skydoor are used to bring sunlight onto solar water cylinders used for heat storage. Heating is provided by radiation and convection from the water cylinders. Auxiliary heat is provided by a small wood burning Franklin stove--needed after 3 sunless days. West windows are shuttered, and an arbor provides summer shade on the south. Cross ventilation provides additional summer cooling. In the sketch here, the high windows are open to let hot air flow out into the summer night.

SLIDE #14 (ROOF POND: DIAGRAM OF ENERGY FLOWS)

In the Roof Pond building type, the storage mass has been relocated to the roof. A body of water is located on the roof, where moveable insulation is used to control its heat gain and loss. Protection from evaporation is usually provided by storing the water in black plastic bags. In climate where freezing is a problem, the water bags are used in a glazed attic enclosure.

SLIDE #15 (ETASCADERO CALIFORNIA CLIMATIC DATA)

The roof pond concept has been used most in the dry climate of the arid southwest. The skytherm house shown next is a good example, since it is provided 100% of its heating by passive construction.

SLIDE #16 (SKYTHERM SKETCH)

Harold Hay has patented the system first used in this all passive 1140 sq foot house. Four 8 ft wide, 38 ft long water filled plastic bags are placed in contact with the steel roof deck, providing a 10 inch depth of water storage. A moveable insulation cover is opened on winter days to collect solar heat for direct radiation through the steel ceiling to the living space. Excess radiant heat is absorbed in massive concrete block floors and walls.

SLIDE #17 (SKYTHERM DIAGRAM)

The Skytherm roof pond system is patented, although other adaptations of the idea are not. The insulating panels are opened and closed automatically. In the summer, the insulated roof panels are opened at night to expose water bags to the cool night air. During the day the cooled water in the ceiling draws heat from the living space and its occupants, and is shielded from the sun by the insulated roof panels. The steel roof deck can also be flooded or sprayed to allow evaporative cooling in the summer. Reversed procedures allow for wintertime heating.

SLIDE #18 (ISOLATED GAIN: ENERGY FLOWS)

The Sunspace ISOLATED GAIN idea allows heat to collect in a space, like a greenhouse, that is not normally used as living area for people. Warmed air in the space can be vented to living area as needed. If wall and floor areas of some dense material are exposed directly to the sun, additional heat storage capacity is gained. During periods when temperatures in the sunroom are not too high, it may be used as direct gain living area.

SLIDE #19 (POPLAR BLUFF, MO. CLIMATIC DATA)

The climate in Poplar Bluff Missouri is quite similar to Atlanta climate. The climate requires both heating and cooling. The residence considered here has a solar assisted heat pump to provide cooling. The house, 77 percent solar heated, has 1304 square feet of living space, including three bedrooms. Living sunspace is on the south, buffered by service and equipment areas to the north.

SLIDE #20 (WATSON HOUSE: SKETCH)

In this hybrid solar system, heat collected from the top of the sun room is moved by a fan to rock storage surrounding the active solar system's water storage. Air from the storage returns to the sun room at a vent just below south-facing windows. An active liquid system uses a solar-assisted heat pump, for both heating and cooling. Cross-ventilation in the house is aided by high vents in the sun room and on the north side of the house.

SLIDE #21 (ALEXANDRIA, VIRGINIA CLIMATIC DATA)

The example selected for this moderate climate in Virginia achieves 60% passive solar heating. It is a sunspace design using a glassed-roof atrium to preheat air for 2115 sq ft of living space. The

southfacing atrium also has high vents which can be opened in summer to create a convective current to cool the space. Look for these features in the next diagram.

SLIDE #22 (RUST HOUSE: DIAGRAM)

This diagram of the house built by Rust Construction Company shows there are very few windows on east and west; more on north side. All inside rooms open to the sunlit atrium. All walls bordering the atrium are 8" masonry to store heat, and the house has a 4" urethane and wood exterior. The roof insulation is R30. The floor of the atrium is stone. There is also an active water system on the roof which transfers heat to a storage tank located on the second floor for later distribution. Domestic hot water is heated through the same system.

SLIDE #23 (ISOLATED GAIN: THERMOSIPHON PRINCIPLE)

A Thermosiphon system uses a collector space which may be separate from the residence itself, (usually) involves some means of storage, and a means of heat distribution. The solar use of the thermosiphoning principle is to allow cooler air or liquid to fall below a collector. When the air in the collector heats up, it rises to be used or stored, drawing more cool air after it across the the collectors. Thermosiphons have been used with good success for both air and water heating.

Heat distribution may be directly from the collector by convection, by radiation from a storage mass, or both.

SLIDE #24 (ALBUQUERQUE, N.M. CLIMATIC DATA)

This is a climate of extremes and yet seventy-five percent of the heating needs of the example house shown next are provided by passive means.

SLIDE #25 (NEW MEXICO THERMOSIPHON: DAVIS HOUSE DIAGRAM)

It contains 1000 square feet of space, arranged about an open interior plan with a loft. Air is heated in the collector and circulated into rock storage supporting the south facing porch. Natural convection moves the heat through the house. Study the diagram to see how the natural flows of the air work to heat the house.

SLIDE #26 (ATLANTA CLIMATIC DATA)

Heating demands are moderate in the Southeast. Supplies of natural gas for heating have been plentiful and relatively low cost. When de-regulation of gas prices occurs, alternative sources for heating will seem much more attractive. The potential for passive and hybrid approaches is quite good for all of Georgia.

SLIDE #27 (PASSIVE SOLAR APPROACHES WORK VERY WELL)

These passive designs are working in many different areas of the country. Some are in areas with more winter insolation than in most areas in the Southeast, some are in areas with much less. The passive approach provides an independent solution to heating and cooling needs--a solution that can work for better southern living.

Collector Components

Answer the following questions:

- a. What is the greenhouse effect? What causes it?

The greenhouse effect refers to the overheating of closed, glassed-in spaces, such as a parked car. It occurs because there is a wavelength conversion when solar energy strikes an absorbent surface. The solar wavelengths are converted to longer wavelengths which are re-radiated to the transparent cover, but are not transmitted.

- b. List two ways in which concentrating and flat plate collectors differ in function.

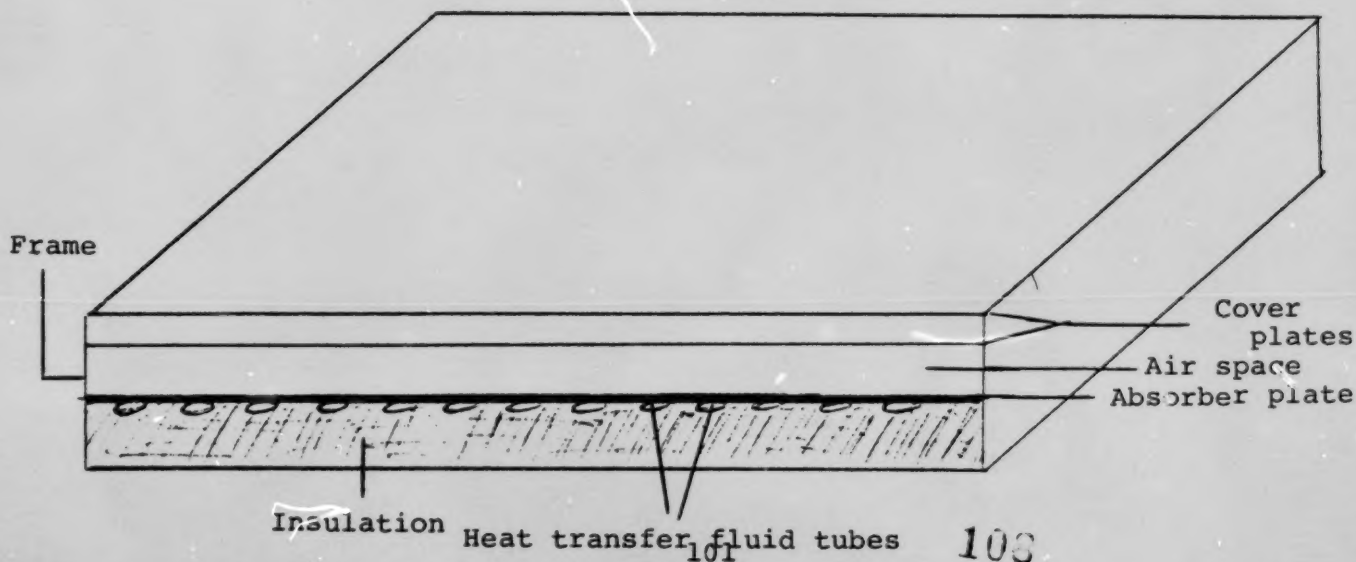
Concentrating

1. gather direct radiation by tracking the sun
2. produce high temperatures

Flat Plate

1. are fixed in position and collect radiation from one direction only
2. produce lower temperatures

- c. In the diagram below, identify each of the major components of a flat plate collector. Is this a one or two cover collector? 2



- d. Would the collector above be more effective in warmer or colder climates? Why?

A two-cover plate collector is more efficient in colder climates. The second cover plate reduces heat loss to the environment, which is important in cold climates. However, the second cover plate also reduces the energy transmitted to the absorber plate, so it should not be used where unnecessary.

- e. How can the efficiency of a transparent cover be increased?

1. reduce reflection from outside surface
2. use materials that absorb less energy
3. coat inner surface with material that will redirect more long wave energy back to absorber plate

- f. Describe factors contributing to the efficiency of the absorber plate. Describe an ideal absorber plate.

1. color
2. thermal resistance to heat transfer system
3. thermal conductance to heat transfer system

An ideal absorber plate has the following qualities:

- absorbs maximal heat energy (95%)
- reflects or radiates minimal energy
- efficiently transfers heat energy to heat transfer fluid
- durable
- low cost

Air vs. Liquid Collectors

Answer the following study questions:

- a. What is the function of the heat transfer system?
It transfers heat from the absorber plate to other areas for storage or distribution.

- b. In air collectors, why are fins, gauze, glass plates, etc., included in the collectors?

They increase the metal-to-air heat transfer surface, and create air turbulence which aids heat conduction from the absorber plate to the air.

- c. In liquid collectors, how does tube configuration affect collector functioning?

Tube configuration affects fluid flow, which should be uniform throughout the collector area for proper collector functioning.

- d. In liquid collectors, should the design allow the liquid to travel up or down when heated? Why?

Liquids should travel up when heated to be consistent with the natural flow of heated liquids. Heated liquids rise.

- e. Describe two possible problems when liquid collectors are used. Briefly mention possible solutions.

1. freezing--use an anti-freeze liquid or a drain-down system.
2. corrosion--use corrosion inhibitors in the liquid.

- f. Describe desirable characteristics for collector insulation material.

low thermal conductivity
low bulk density
high melting point
resistant to rot, weather, insects, rodents

- g. Describe desirable characteristics for collector frames.

Must seal other components against the weather and climate; must be able to expand and contract with temperature changes; must be durable and strong.

- h. In the chart below, indicate the advantages and disadvantages of air vs. liquid systems.

	<u>Advantages</u>	<u>Disadvantages</u>
Air Solar System	Lower capital costs. No corrosion, clogging, or anti-freeze solutions. Leaks have less severe consequences. Domestic hot water system is not subject to contamination by leaks from the heat storage unit.	Duct work risers occupy usable floor space. More energy required to move solar energy from collector to storage to use. Installation must be leak tight which is less obvious than with water systems.
Liquid Solar System	Water is cheap & efficient heat transfer & storage medium. Piping uses little floor space. Circulation of water uses less energy for equal heat content. Adaptable to large bldgs. Can provide energy for cooling.	High initial cost. Corrosion, scale or freeze can occur causing damage or blockage. Leakage can cause considerable damage to the system & dwelling. Contamination of water supply is possible if poor design allows treated water in storage to enter domestic water system. Summer boiling can be problem.

Answer the questions below. Refer to the collected data to support your answers.

a. When was T_f the highest? Why was this so?

b. Which seemed most important to temperature increases: The nature of the absorber surface, the number of cover plates, or the time of day? Explain your response.

c. Why were the collectors tilted and oriented in an identical manner?

The collectors were tilted and oriented identically to insure they received the same amount of solar radiation.

d. If the outdoor temperature had been much colder, would there have been a bigger difference in T_f for one versus two cover plates? Why?

If outdoor temperature were colder, the difference between the one and two cover plate collectors would increase. The two plate collector has an advantage for heat collection colder climates in that the second plate reduces heat loss to the environment.

e. How could the collectors have been better designed to capture more heat?

"Instructor's Materials"

See Fundamentals of Solar Heating, Figure 3-4 for a cross-sectional drawing. The following parts and their qualities should be indicated:

1) transparent covers

- a. should be enough in number to reduce heat loss for climate of use
- b. should transmit incoming radiation, with minimal reflection or absorption
- c. should not transmit radiation reflected back from absorber plate
- d. must be capable of withstanding environmental abuse, and heat generated internally by the collector

2) absorber plate

- a. should absorb maximal radiation, and reflect or radiate energy minimally
- b. should not resist heat transfer to transfer medium
- c. should conduct heat to transfer medium
- d. coating should be able to withstand high temperatures

3) space between covers, or between cover and absorber plate

- a. should be air-tight
- b. should be about $\frac{1}{4}$ -inch

4) insulation

- a. should have low thermal conductivity
- b. should be of low bulk density
- c. should have high melting point
- d. should be resistant to rot, weather, insects and rodents
- e. may be of fiberglass or polyurethane foam

5) frame

- a. must be durable and strong
- b. must be able to expand and contract
- c. must seal other components from environment

Collector Loops

Answer the study questions below:

- a. What is the "collector loop?"

The collector loop includes the collectors and all other components through which the collector fluid must travel between the time it leaves and returns to the collector.

- b. What is the difference between an open and a closed loop?

In an open, but not a closed-loop, the liquid in the collector is exposed to the air at some point.

- c. List advantages and disadvantages to open loops and to closed loops, using the table below.

	<u>Advantages</u>	<u>Disadvantages</u>
Open Loop	Often circulate water, which is an inexpensive loop liquid.	Exposure of liquid to air may promote system corrosion. Require more powerful pumps.
Closed Loop	Require less powerful pumps. Less subject to internal corrosion.	Liquid is more costly, since it must be protected from freezing by inclusion of an anti-freeze.

Liquid Collectors

Answer the following study questions:

- a. Circle the seven (7) metals which are most easily corroded in aqueous solutions: silver, brass, copper, zinc, steel, platinum, bronze, iron, tin, graphite, magnesium, gold, aluminum, chromium-iron, lead, cast iron

- b. Why is it inadvisable to circulate acidic water in collectors? What corrective measures should be taken?

Corrosion is more rapid in acidic, than in basic or neutral solutions. Acidic water should be drained and replaced.

- c. Why is corrosion less in an air-tight collector loop?

The liquid is not exposed to air, so there is less oxygen in the liquid to promote corrosion.

- d. What concentration of corrosion inhibitor is recommended? What is the resulting pH level (a measure of acidity)?

In water, the recommended concentration level of a corrosion inhibitor should be about 1.5% by weight, giving a pH of between 7.5 and 8.

- e. If automotive grade antifreeze (ethylene glycol) is used to inhibit corrosion, what percent concentration of it in the water is necessary?

A 30% concentration of automotive grade ethylene glycol in water can be used to prevent corrosion.

- f. Describe considerations for using filters.

To initially filter the liquid, a 50 micron filter may be used. However, this may cause undesirable pressure drop, so later a 350 micron filter should be used.

- g. Why is ion getter used?

An ion getter minimizes ion exchange between metals, thus reducing corrosion.

- h. What percent of ethylene glycol should be included in a liquid system to avoid freezing?

10-20%

- i. Why must pipes leading to the collector be insulated?

To avoid liquid freezing in the pipes.

- j. If ethylene glycol is used as both a corrosion inhibitor and an antifreeze, what should be its minimum concentration in the water?

30%

- k. What factors cause decomposition of ethylene glycol?
What can be done to minimize such decomposition?

High temperatures--In the absence of dissolved oxygen, temperatures above 300° F should be avoided. The maximum temperature is lower (250° F) if dissolved oxygen is present in the liquid. Presence of air in the liquid speeds decomposition. To avoid decomposition: regulate liquid temperature, use anti-oxidants, avoid liquid oxidation.

1. What problems may be caused by exposure of the collector liquid to air?
1. breakdown of collector liquid is promoted
 2. internal corrosion is promoted
 3. fluid viscosity may increase
 4. insoluble materials may be formed, which may hamper system performance.

Collector Efficiency

Answer the study questions below:

- a. What is the efficiency of a collector having an input of 8000 Btu/h and an output of 7000 Btu/h?

$$\frac{\text{output}}{\text{input}} = \frac{7000}{8000} = .875$$

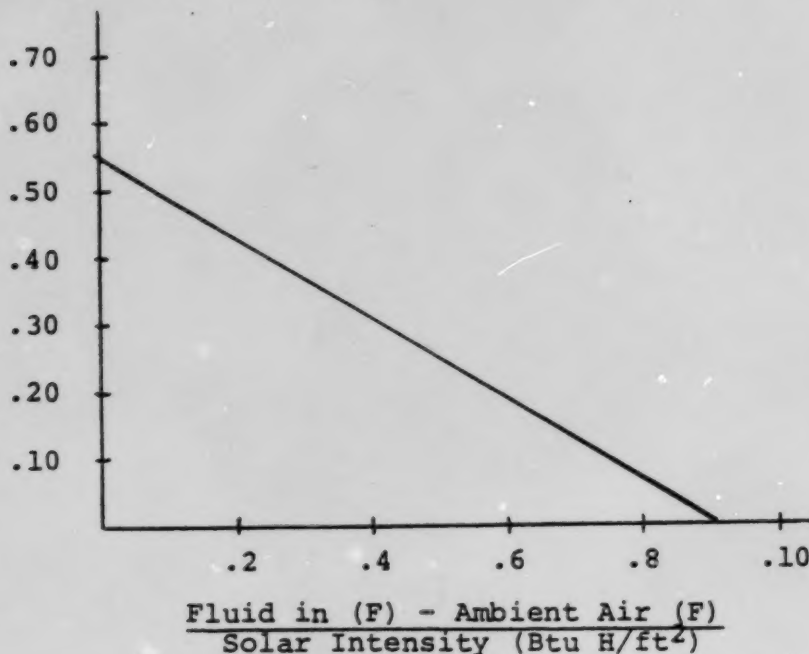
- b. List two operating conditions under which collector efficiency is decreased.
- 1) if the fluid inlet temperature and solar intensity are constant, but the outdoor temperature decreases
 - 2) if fluid inlet temperature increases
- c. Why is the average collector efficiency usually less than the efficiency published in the manufacturers specifications?

The published data represents performance at or near solar noon when the sun is most directly overhead.

- d. In the diagram below, plot the efficiency curve for a collector having the following characteristics:

Intercept = .55

Slope = .60 (or 6/10)



- e. What is the efficiency of the collector described above under the following conditions:

Fluid temperature = 110°F

Ambient air temperature = 40°F

Solar intensity = 300 Btu H/ft^2

Efficiency = .41 $\left(\frac{110 - 40}{300}\right) = .23$

- f. If fluid inlet temperature of the above collector is 130°F , what is the collector efficiency?

The collector is less efficient when the input fluid temperature is 130°F , than when the input temperature is 110°F .
 $\left(\frac{130 - 40}{300}\right) = .30$
 Efficiency = .37

- g. List the appropriate fluid flow rate for air and liquid collectors.

Liquid collector

Air collector

Fluid Flow Rate

0.2 ga./min./ft^2 of collector

$2\text{-}3\text{ ft}^3\text{/min./ft}^2$ of collector

1. Circle T or F to indicate whether each of the following statements is true (T) or false (F). (3 1/3 points each.)
 - a. T F Flat plate collectors can be placed on any part of the roof, and still operate effectively.
 - b. T F Concentrating collectors pivot during the day.
 - c. T F Most radiation that strikes a collector is absorbed by the cover plate.
 - d. T F The average annual temperature helps determine the number of cover plates necessary on a collector.
 - e. T F Liquid collectors are larger than air collectors because of the space needed for piping.
 - f. T F A black absorber plate should absorb about 90% of the radiant energy.
 - g. T F Fluid should travel upward in a liquid collector.
 - h. T F A selective absorber surface increases reradiation of infrared energy from the absorber plate.
 - i. T F Concentrating collectors are referred to as low temperature collectors.
 - j. T F Flat plate collectors absorb direct and diffuse radiation.
 - k. T F The inner surface of the cover plate of a collector should transmit long wave radiation.
 - l. T F Flat plate collector temperatures usually achieve a maximum of about 150° F.
 - m. T F A closed collector loop requires smaller pumps than an open collector loop.
 - n. T F Corrosion is more of a problem in an open loop system.
2. a) Two problems that may occur in liquid, but not air systems are freezing and corrosion. (6 2/3)
- b) The basic parts of a solar collector are: (3 1/3 points each.)

1. <u>cover plate</u>	4. <u>frame</u>
2. <u>absorber plate</u>	5. <u>heat transfer fluid (Or tube)</u>
3. <u>insulation</u>	

- c) The heating within a collector, and the heating of the inside of a car by solar radiation are both examples of the greenhouse effect. (3 1/3)
- d) To increase transmittance of heat from the absorber plate to the air, air collectors usually include _____.
(fins, gauze, glass plates, or irregular surface) (3 1/3)
- e) Two advantages of liquid systems, as compared to air systems are: (3 1/3 each)
- a. (piping takes little space; water is a cheap and efficient transfer medium; less
 - b. energy is required for liquid circulation; can be used for cooling)
- f) A flat plate solar collector captures the most heat energy during the day at solar noon. (not clocktime noon)(3 1/3)
- g) A closed collector loop is one in which the liquid is not exposed to air. (3 1/3)
- h) A filter is used to strain particles out of the liquid in a collector loop. (3 1/3)
- i) Two cover plates are generally used in flat plate collectors if the annual temperature averages below 50°F.
(3 1/3)
- j) When ethylene glycol is used as both an antifreeze and corrosion inhibitor, its minimum concentration should be 30%. (3 1/3)

FLAT PLATE SOLAR COLLECTORS:
FACTORS AFFECTING PERFORMANCE
PART I

Numbers at end of slide callout refer to slides from the Solar-Ed Slide Library, Flat Plate Solar Collectors, Catalogue #SL-10C, available from Solar-Ed, Woodbridge, Connecticut.

SLIDE #1 (Slide set title slide)

The flat plate solar collector is the type of collector most commonly used in residential installations. Let us look at how different factors affect the function of flat plate collectors.

SLIDE #2 (Photo of two collectors mounted on roof-1)

Here we see two flat plate collectors which are used to heat domestic hot water.

SLIDE #3 (Graph of radiation as function of season, time of day-2)

The amount of heat these collectors will be able to provide is determined by a variety of factors. On a horizontal surface, more insolation occurs in summer than in winter, and toward noon, rather than earlier or later in the day.

SLIDE #4 (Diagram of sun's location in sky in summer and winter-3)

The sun travels lower in the sky in the winter, which reduces the amount of insolation received by a horizontal surface in the winter. To compensate for this, the collector is tilted so as to increase the amount of insolation received in the season when solar energy is needed.

SLIDE #5 (Table of insolation for different cities-4)

The amount of solar radiation varies not only with season, but also with geographical location. Insolation increases when a location is towards the equator, has relatively clear weather, and a high altitude.

SLIDE #6 (Schematic of collector cross-section-8)

We have seen that season, time of day, and location affect flat plate collector performance by affecting the amount of radiation received. Characteristics of the collector itself also affect its performance. Here we see a diagram of the major components of a flat plate collector.

SLIDE #7 (Table of transmittance of different coverplate materials-11)

The outer cover plate, or plates of the collector affect its performance by determining the amount of energy that is transmitted to the heat absorbing plate. Cover plates of different materials vary in their energy transmitting abilities.

SLIDE #8 (Drawing illustrating how cover plates increase efficiency-51)

The efficiency of a collector is increased when a cover plate is used. Efficiency describes the amount of heat output from a collector, compared to the amount of solar heat available to the collector.

SLIDE #9 (Schematic drawing of collector cross-section-16)

In areas where outdoor temperatures are cold, usually below 50° F, two cover plates are used. The cover plates are necessary to trap heat energy within the collector. They minimize air currents across the absorber plate that might cause heat loss because of convection.

SLIDE #10 (Photo of cross-section of collector-14)

Let's look at the cover plates in some real collectors. In this cutaway view, the outer cover plate is made of acrylic or plastic, and the inner glazing is made of a plastic film. Notice, also, the absorber plate, with copper fluid tubes, the insulation behind the absorber plate, and the aluminum extruded frame.

SLIDE #11 (Photo of cross-section of collector-18)

In this collector, the outer cover plate is made of glass, and the inner cover plate is a plastic film. This design is often used in areas where the collector must withstand severe weather, making scratchable plastic inappropriate for the outer cover plate.

SLIDE #12 (Photo of cross-section of collector-17)

This cutaway shows very clearly the double cover plates, and also the galvanized enclosure of the collector.

SLIDE #13 (Photo of cross-section of collector-15)

This is a cross section of the Daystar solar collector. At the front of the collector is a folded sheet of plastic that looks like an accordion type bellows. This plastic folded glazing traps heat and forms a very effective insulating layer to prevent energy from escaping from the collector.

SLIDE #14 (Photo of copper absorber plate-27)

Another collector component which affects its performance is the absorber plate. Here is a copper absorber plate used in a liquid collector made by Revere. Fluid travels through flattened copper tubing soldered to the absorber plate.

SLIDE #15 (Graph showing temperature profile across absorber plate-23)

In this slide, the temperature profile of a collector absorber plate, such as the Revere collector, is shown. Where the fluid is in contact with the plate, the temperature is lowest as heat is carried off by the fluid.

SLIDE #16 (Drawing showing relation between angle of incidence and radiation transmitted-12)

The amount of heat transmitted to the absorber plate depends on the kind and number of cover plates used, and on the angle at which solar radiation strikes the cover plate. As shown here, more solar energy is transmitted to the absorber plate when the radiation strikes the collector at a perpendicular angle.

SLIDE #17 (Table showing heat transmission by different materials-20)

An important function of the absorber plate is to transmit heat energy to the fluid that will transfer heat to other parts of the system. As we see here, copper and galvanized steel absorber plates transmit a relatively high percent of the heat they absorb. Aluminum absorber plates are less effective.

SLIDE #18 (Drawing showing how selective coatings improve collector performance-28)

In addition to the metal chosen for an absorber plate, the coating placed on the metal is also very important. A selective coating is expensive, but traps more heat than a black paint coating.

SLIDE #19 (Photo of collector with copper absorber plate-31)

Now let's look at some absorber plates. Here is a cross-section of a Grumman solar collector that uses a copper absorber plate. Remember that copper very effectively transmits heat to the fluid in the tubes in the plate.

SLIDE #20 (Photo of Olin Roll-Bond--21)

Olin Roll-Bond may be used for absorber plates. The thermal fluid passes through the channels, which are an integral part of the absorber sheets. Fluid tubes must be integral to, or carefully bonded to the absorber plate. Otherwise, heat transfer is reduced.

SLIDE #21 (Photo of collector made of Olin Roll-Bond--22)

Here is a collector made of Olin Roll-Bond. Notice that the sheet is manifolded together at the end and then piped out of the collector.

SLIDE #22 (Photo of aluminum tubing-24)

This is an extruded aluminum finned tubing that can be made into an absorber plate.

SLIDE #23 (Photo of aluminum tubing made into collector-26)

Here, the aluminum tubing has been flattened, cut to length, and painted with a selective absorbing coat.

SLIDE #24 (Photo of collector interior-29)

This collector has been made by clamping an aluminum absorber plate onto copper tubing. Although this is a very inexpensive way to manufacture absorber plates, the contact between the copper and aluminum can lead to corrosion problems.

SLIDE #25 (Photo of two collectors mounted on rack-13)

We have now examined some of the factors that affect flat plate collector performance. These include the amount of solar radiation received, and qualities of the cover and absorber plates.

FLAT PLATE SOLAR COLLECTORS:
FACTORS AFFECTING FUNCTION
PART II

Numbers at end of slide callout refer to slides from the Solar-Ed Slide Library, Flat Plate Solar Collectors, Catalogue #SL-10C, available from Solar-Ed, Woodbridge, Connecticut.

SLIDE #1 (VMC Title Slide)

(Music up for about five to ten seconds. . . then down under next frame's narration.)

SLIDE #2 (Slide Set title slide)

We have already seen that collector function is affected by season, time of day, geographical location, and qualities of the cover and absorber plates. Other factors also contribute to collector performance.

SLIDE #3 (Graph of heat transfer as a function of fluid velocity-25)

The rate at which the heat transfer fluid travels through the collector is one such factor. The higher the fluid velocity, or speed, the more quickly heat is absorbed and carried away from the absorber plate.

SLIDE #4 (Graph of freezing point as a function of percent of ethyl glycol-34)

A variety of types of heat transfer fluids are available for liquid collectors. Often, ethylene glycol is added to water to avoid freezing. The more ethylene glycol, the lower the freezing point of the solution. A 30 percent concentration of ethylene glycol is usually adequate.

SLIDE #5 (List of heat transfer liquids-32)

Here are some other frequently used liquid transfer fluids. The usable temperature range of the fluid should be considered in selecting a fluid for a particular system.

SLIDE #6 (Liquid thermosyphon system-37)

In active liquid systems, the heated fluid is circulated by pumps. However, a passive liquid system may depend on the rising of the heated liquid to promote circulation. A thermosyphon system depends on liquid convection to circulate fluid through the collectors.

SLIDE #7 (Air thermosyphon system-38)

Passive air thermosyphon systems are also possible.

SLIDE #8 (Air system heat absorber configurations-39)

In air systems, heat transfer is promoted by special absorber plates. These increase the absorber plate surface and turbulence in the air as it passes across the absorber plate. This promotes transfer of heat from the absorber plate to the air.

SLIDE #9 (Air collector folded absorber plate-40)

Here is an air collector showing a folded absorber plate. Air is blown across both sides of the plate, increasing its contact with the plate.

SLIDE #10 (Cross-section of Sunworks collector-43)

A Sunworks air collector has a corrugated absorber plate through which air is blown. Note the black, rubber gasketing used for connecting the collector to the main air duct.

SLIDE #11 (Cross-section of collector-44)

Finally, the insulation and frame of the collector are important to its functioning. The frame must be strong and must allow for the expansion and contraction that occur with heating and cooling. This collector has an extruded aluminum frame.

SLIDE #12 (Cross-section of collector-30)

The insulation below the absorber plate must be durable, and must not degrade under conditions of extreme heat.

SLIDE #13 (Collector array on roof-60)

In sum, all of the components of a solar collector are important to its performance. In designing effective solar systems, collectors must be carefully analyzed. Detection of collector strengths and weaknesses can promote excellence in system design.

Introduction to Heat Storage

Answer the study questions below:

- a. What is the meaning of the term, "specific heat?"

Specific heat describes the ability of a material to absorb heat.

- b. What is the specific heat of water? of rock?
What consequence does this difference have for the size of water storage versus rock storage units?

Specific heat of water = $1.0 \text{ Btu/lb/F}^\circ$

Specific heat of rock = $.20 \text{ Btu/lb/F}^\circ$

A given volume of water can absorb more heat than the same volume of rock. In choosing a storage unit capable of absorbing a fixed amount of heat, a water storage tank can be smaller than a rock storage bed.

- c. How does heat storage occur in a phase change storage system?

The storage material is capable of absorbing heat as it changes state from solid to liquid to gas. The release of heat causes a change of state in the opposite direction.

- d. With current technology, phase change storage is not frequently used. Why is it not often used?

Phase change storage materials are expensive. Although the storage material volume may be small, a larger area is necessary for heat transfer to the material.

e. What considerations should determine the choice of a storage medium?

- 1) Ability of different substances to absorb heat
- 2) cost of material necessary to satisfy heat
- 3) demand availability of the material.

Storage Size and Heat Absorption

Answer the study questions below:

- a. Calculate the number of Btu's absorbed by a 1000 ga. water storage tank which increases in temperature from 140° to 160° F.

$$\begin{array}{l} \text{Volume of} \\ \text{Storage Unit} \end{array} \times 8.34 \text{ lb/ga} \times 1 \text{ Btu/lb} \times (\text{final} - \text{initial} \\ \text{temperature}) =$$

$$1000 \text{ ga} \times 8.34 \text{ lb/ga} \times 1 \text{ Btu/lb} \times (160-140) =$$

$$166,800 \text{ Btu} = \text{Number of Btu's absorbed.}$$

- b. Note that 1000 gallons is approximately 135 ft³. Calculate the number of Btu's absorbed by a 135 ft³ rock storage unit which increases in temperature from 140° F to 160° F.

$$\begin{array}{l} \text{Number of Btu's absorbed} = \\ \text{Volume of} \\ \text{Storage Unit} \end{array} \times 100 \text{ lb/ft}^3 \times .20 \text{ Btu/lb} \times (\text{final} - \text{initial} \\ \text{temperature}) =$$

$$135 \text{ ft}^3 \times 100 \text{ lb/ft}^3 \times .20 \text{ Btu/lb} \times (160-140) =$$

$$54,000 \text{ Btu} = \text{Number of Btu's absorbed.}$$

- c. Which type of storage unit absorbed more heat?

water storage tank

- d. How large would the rock storage unit need to be to absorb the amount of heat absorbed by the water storage unit? Number of Btu's absorbed =

$$\begin{array}{l} \text{Volume of} \\ \text{Storage Unit} \end{array} \times 100 \text{ lb/ft}^3 \times .20 \text{ Btu/lb} \times (\text{final} - \text{initial} \\ \text{temperature}) =$$

$$166,800 \text{ Btu} = \text{Volume} \times 100 \text{ lb/ft}^3 \times .20 \text{ Btu/lb} \times 20$$

$$\frac{166,800}{100 \times .2 \times 20} = \text{Volume } 129.417 \text{ ft}^3$$

135

"Instructor's Materials"

UNIT SB-4
PROGRESS CHECK (C-1)
(written quiz)

- a. The specific heat of water is 1.0 Btu/lb/F⁰.
- b. Rock has a (lower, higher) specific heat than does water.
- c. Storage systems which involve materials that change from solid to liquid during heat storage are known as phase change storage systems.
- d. Heat absorbing materials that change from solids to liquids are (more, less) expensive than sensible storage materials.
- e. To absorb a given amount of heat, a (rock, water) storage unit would have to be larger.
- f. How many Btu's are absorbed by a 150 ft³ rock storage unit during a temperature change from 110⁰ to 140⁰ F? Apply the formula listed below.

$$\begin{aligned}\text{Number of Btu's absorbed} &= 150 \times 100 \times .2 \times 30 \\ &= 90,000\end{aligned}$$

$$\begin{aligned}&\text{Volume of} \\ &\text{Storage Unit} \times 100 \text{ lb/ft}^3 \times .20 \text{ Btu/lb} \times (\text{final-initial} \\ &\quad (\text{ft}^3) \quad \quad \quad \text{temperature})\end{aligned}$$

Question Sheet

1. The ice chest cover functioned as the cover plate in a real solar system.
2. The black container functioned as the absorber plate in a real solar system.
3. The rocks/water function as the heat storage material in a real solar system.
4. The ice chest functioned as the insulation in a real solar system.
5. Why were the ice chests tilted and faced south?
to maximize the amount of insolation
6. Why were the cans painted black?
to increase the amount of heat absorbed by the can's
surface
7. At what time of the day were the storage temperatures the highest for each storage unit? Why?
8. Was there a difference between the air temperature inside the ice chest and outside the ice chest? Why did this occur?

9. Toward the evening, in which ice chest did air temperature drop more slowly? Why did this occur?

10. Which storage unit reached its highest temperature first? Why?

Sizing Storage Units

Answer the study questions below:

- a. What two factors should determine the volume of space for storage?

size of collector area

size of building (heat load)

- b. What happens if the storage size is too large, relative to collector heat absorption?

The storage tank may take too long to be heated to temperature that is usable for space or water heating.

- c. What happens if storage size is too small, relative to collector heat absorption?

The storage tank may become overheated. If the fluid returning to the collector from the storage tank is too hot, collector efficiency is reduced.

- d. Cite the general rule for estimating a) water storage size from collector size, b) rock storage size from collector size.

For water storage: use one to two gallons of water per square foot of collector area

For rock storage: use one-half to one cubic foot of rock per square foot of collector area

- e. In a particular solar system, the collector area is 192 square feet.

1. Estimate the size of necessary water storage in cubic feet. (1 gallon has a volume of about .135 ft³)

$$192 \text{ ga} \times .135 = 25.92 \text{ ft}^3$$

$$384 \text{ ga} \times .135 = 51.84 \text{ ft}^3$$

192 to 384 gallons

2. Estimate the size of rock storage.

86 to 192 cubic feet of rock

Sizing Storage Units

If overnight building heat loss is 227,000 Btu, and storage temperature rises 40° F, what size of storage is necessary for:

- a. Water storage (in ft³)? (1 gallon has a volume of .135 ft³)

$$\begin{aligned} \text{Number of gallons} &= \frac{\text{Overnight heat load (Btu)}}{8.34 \text{ lb/ga} \times 1 \text{ Btu/lb} \times \text{Storage Temperature Change}} \\ &= \frac{227,000 \text{ Btu}}{8.34 \text{ lb/ga} \times 1 \text{ Btu/lb} \times 40^\circ\text{F}} \\ &= 680.5 \text{ ga} \end{aligned}$$

$$680.5 \text{ ga} \times .135 \text{ ga/ft}^3 = 91.87 \text{ ft}^3$$

- b. Rock storage?

$$\begin{aligned} \text{Number of ft}^3 &= \frac{\text{Overnight Heat load (Btu)}}{100 \text{ lb/ft}^3 \times .2 \text{ Btu/lb} \times \text{Storage Temperature Change}} \\ &= \frac{227,000}{100 \text{ lb/ft}^3 \times .2 \text{ Btu/lb} \times 40} \\ &= 2837.5 \text{ ft}^3 \end{aligned}$$

Locating Storage Units

Answer the study questions below:

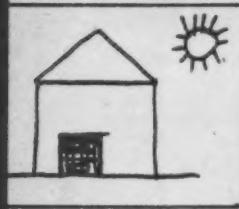
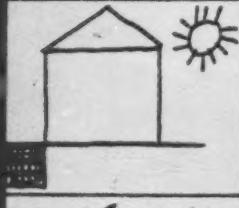
- a. What is the overall, basic rationale that should be applied in choosing a location for a storage unit?

Place the storage unit in a low value area.

- b. Four different types of storage locations are described:

1. Inside the building, below grade
2. Inside the building, above grade
3. Outside the building, below grade
4. Outside the building, above grade

In the chart below, indicate the advantages and/or disadvantages of each location.

Advantages	Disadvantages
 ← Storage Unit - close to other components - protected from moisture/cold - excessive heat can be directed to space or vented outdoors	- may be difficult to install in a built house
 - excessive heat may be directed to space or vented	- extensive foundation reinforcement may be necessary to support weight - may be difficult to install in a built house
 - avoids use of space inside - avoids concern for aesthetic appeal of unit - may be used for retrofit or new construction	- should be buried below frost-line to avoid pressure from freezing soil - difficult to locate leaks - must be well insulated to prevent heat loss
 - may be used for retrofit or new construction - is easily accessible for repair - avoids use of interior space	- less protected from moisture or must be well insulated to /cold prevent heat loss - may be aesthetically unappealing - less protected from moisture or cold

CHARACTERISTICS OF WATER & PEBBLE
STORAGE UNITS

Answer the study questions below:

a. Describe three advantages of water storage.

- 1) Water is abundant and inexpensive.
- 2) Water absorbs and emits heat readily.
- 3) The space requirements for water storage are the least for any common storage medium.

b. Describe five disadvantages of water storage.

- 1) The system must be insulated against freezing.
- 2) There must be safeguards against boiling.
- 3) The system must be frequently checked for leaks.
- 4) Safeguards against corrosion of pipes and components must be implemented.
- 5) The storage tank must easily be accessible for repair and maintenance, since malfunction can cause severe damage.

c. Describe the methods commonly used to minimize problems associated with each of the disadvantages listed above.

- Use insulation and anti-freeze to avoid freezing.
- Install a ventilating valve to relieve pressure caused by boiling.
- Periodic inspection can lead to early detection of leak.
- To avoid corrosion--use a corrosion inhibitor in the liquid
use plastic pipes or dielectric unions
with plastic bushings between incompatible metal components
- Place storage tank in an accessible location and inspect often.

d. Describe the kinds of problems which may occur with each of the following kinds of storage tanks:

1. Concrete tank - may be very large and heavy, and difficult to install; watertight pipe connections are difficult to achieve without using high quality caulking compounds, such as silicone
2. Fiberglass tank - may rupture at high temperature or pressure
3. Glass-lined tank - can crack or break easily during installation
4. Galvanized tank - may become corroded over time

e. Describe ways to construct pebble beds containers.

lay concrete blocks and fill holes with concrete
pour concrete into a form
fabricate from wall stud material, plywood and insulation

f. Why should the pebbles be hand shoveled or carefully chuted into the supporting container?

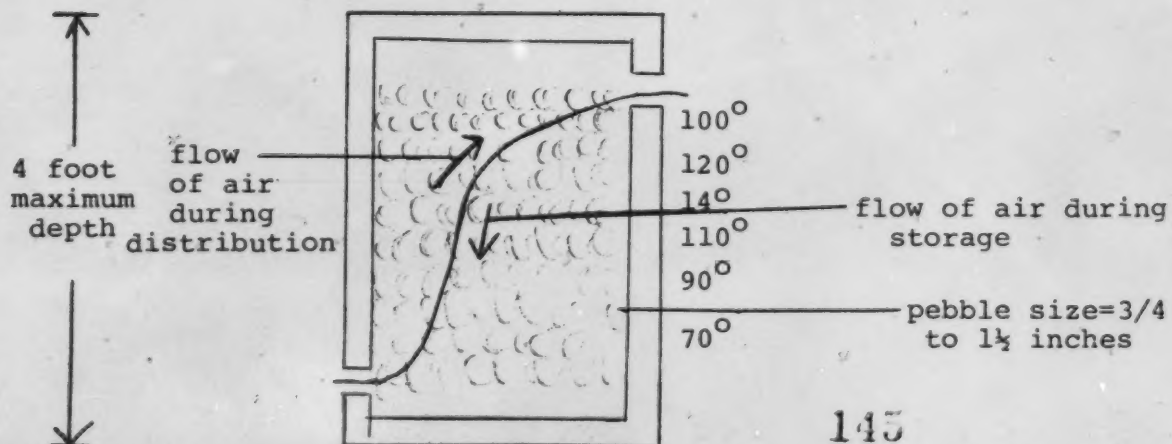
to insure even distribution and reduce packing or side wall stress

g. Why are cubic pebble beds preferred over horizontal pebble beds?

because heat has a natural tendency to rise;
cubic beds allow more vertical space within which thermal stratification may occur.

h. In the space below, illustrate an ideal pebble bed and its operation. You should label your drawing to indicate the following:

pebble size
pebble bed depth
the flow of air during heat storage
the flow of air during heat distribution
the thermal stratification of the storage bed



Comparing Real & Model Storage Units

- 1) In the activity of Job Sheet SB-4-1, you built and observed the operation of simple water and pebble storage units. Compare these simple units to real water and pebble storage units, in terms of components and operation. How are the simple units different from real units? How are they similiar?

You may use the table below to present your ideas.

	Model Storage Unit	Real Storage Unit
Components	Black, heat-absorbing container storage medium	Storage medium Container Insulation Opening for fluid to enter & leave
Means for gathering heat for storage	Heat is absorbed from storage container walls.	Heat is absorbed from a fluid heated in a separate collector, and circulated from the top of storage to the bottom.
Means of distributing heat to air space	Heat is distributed to space in chest by means of radiation through storage unit walls.	The storage fluid is circulated from bottom to top, or heats another fluid which is circulated to heat air in spaces.

- 2a) In a real liquid storage unit, the following minimal storage temperatures are necessary

for space heating: 90°F

for water heating: 60°F

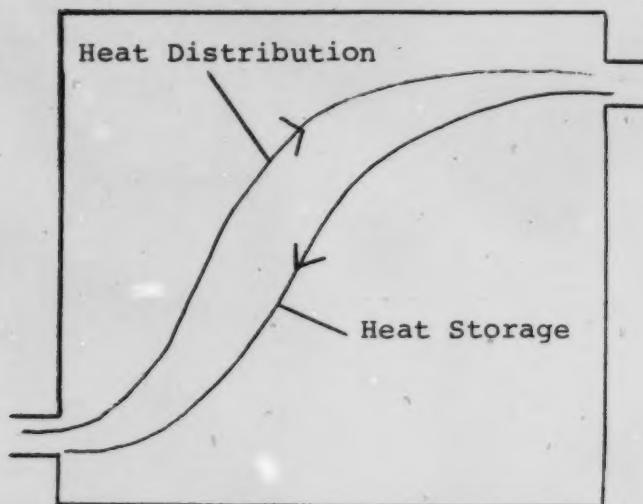
for space cooling: 180°F

- b) How are the maximum allowable liquid storage tank pressure and the maximal critical temperature related?

The higher the maximum allowable pressure, the higher the internal temperature can be.

- 1) Indicate whether each statement is true or false by circling T (true) or F (false). (3 1/3 points each.)
- a. T F Rock storage usually takes up less space than liquid storage.
 - b. T F Rock has a lower specific heat than water.
 - c. T F To retain a comparable amount of heat energy, wax requires a larger heat storage tank than water.
 - d. T F Phase change storage systems are not presently used as often as sensible heat storage systems.
 - e. T F The first consideration in locating a storage unit is that it be very close the collectors.
 - f. T F If a storage unit is too small for a system, overheating may occur.
 - g. T F Heat storage system sizes are determined by the average daily temperature in January.
 - h. T F An advantage to concrete storage tanks is that watertight connections are easy to make.
 - i. T F One problem with locating storage units below grade is that they may be difficult to access for repair.
 - j. T F Galvanized steel storage units suffer the disadvantage that they may corrode over time.
 - k. T F Cubic pebble beds are preferred over horizontal pebble beds.
 - l. T F A moderately priced storage tank can be designed so that the solar system can satisfy 90% of the space heating demand.

- 2) In the diagram below, indicate with arrows the direction of fluid flow
- during heat storage (3 1/3 points)
 - during heat distribution to spaces (3 1/3 points)



- 3) Fill in the blanks with the correct response. (3 1/3 points each correct answer.)
- The ability of a material to absorb heat is described numerically by its specific heat.
 - A storage system in which a material changes from a solid to a liquid as it absorbs heat is known as a phase change storage system.
 - The size of the storage unit depends on two factors: the collector area and the heat load.
 - In storage units, there are differences in the amount of heat stored in different layers of the storage material, with the most heat being stored in top layers. This is known as thermal stratification.

- e. In a water storage unit, the minimum temperature useful for space heating is about 90° F.
- f. Two practical locations for a storage unit in a house are in attic or in basement. (or crawl space)
- g. One problem with water storage units, but not rock storage units is (see below). However, rock storage units have the disadvantage that they take up more space and have a lower specific heat.
(corrosion, freezing, leaking)
- 4) How many Btu's are absorbed by a 1000 gallon water storage unit in a temperature change from 150° F to 180° F?
(3 1/3 points)

$$\text{Number of Btu's absorbed} = 1000 \times 8.34 \times 1 \times 30 = 250,200$$

$$\text{Volume of Storage Unit} \times 8.34 \text{ lb/gal} \times 1 \text{ Btu/lb} \times (\text{final-initial temperature})$$

- 5) If a collector array is 500 square feet, what is the largest water storage tank that should be used? (3 1/3 points)

$$2 \text{ gal/ft}^2 \times 500 \text{ ft}^2 = 1000 \text{ gal.}$$

- 6) List two possible problems with water storage units, and indicate a method for minimizing each problem.
(3 1/3 points each correct answer)

freezing--include an anti-freeze solution, insulate

corrosion--use corrosion inhibitors, plastic piping, dielectric unions with plastic bushing

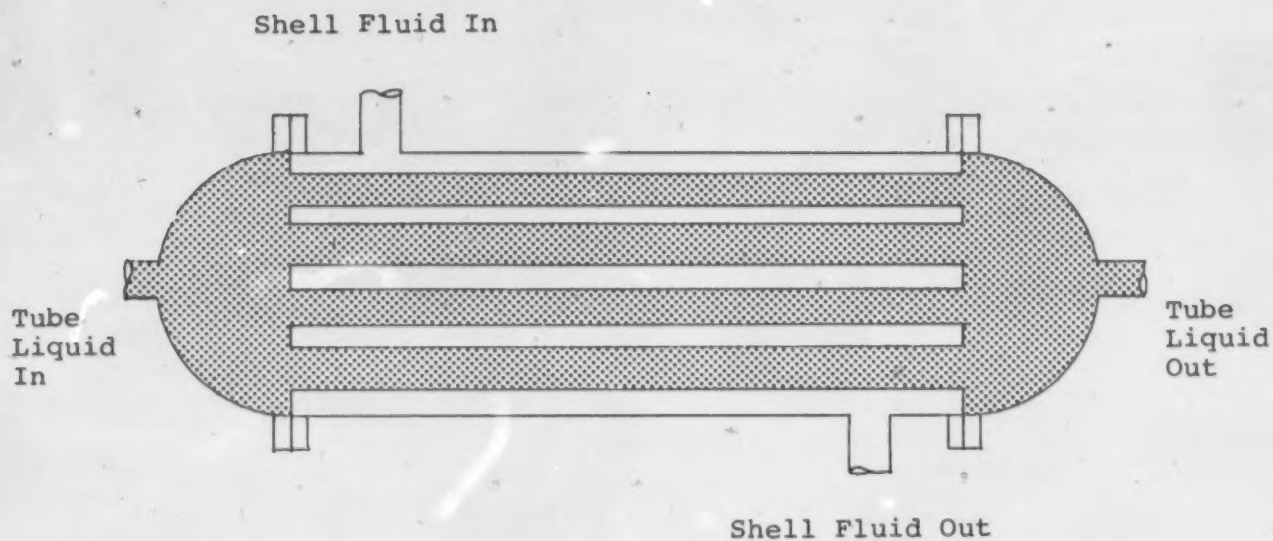
boiling--install a ventilating valve

leaks--inspect the system periodically

- a. Specifications for pumps usually describe the following characteristics of the pump: the gallons/min. and HP rating of motor.
- b. A type of pump usually used in solar systems is called a centrifugal pump.
- c. Head pressure refers to: the ability of the pump to overcome system resistance
- d. Do open or closed loops require more powerful pumps? Why?
Open - The pressure of liquid leaving the collector is not helpful in pushing liquid back up to the collector. An open loop pump must overcome flow resistance when the system is being refilled after drain-down.
- e. In measuring pressure, one foot of water = .43 pounds per square inch (psi).
- f. Pump capacity (increases, decreases) as resistance increases.
- g. Pumps in collector loops should be able to stand pressures of 150 psi, and temperatures of 200.
- h. Open loop system pumps should be made of bronze or to minimize corrosion. stainless steel
- i. A pump made of iron may be used in closed loops.
- j. How do two-speed pumps improve collector efficiency?
The pump can run on "high" to more efficiently remove heat from the collector when insolation is high. The pump can run more slowly when insolation is less.
- k. What is the purpose of including a heat exchanger between the collector and storage loops of a liquid system?
The inclusion of a heat exchanger between collector and storage loops makes it unnecessary to include high concentrations of antifreeze in the storage loop and tank, which are less vulnerable to freezing. Use of less antifreeze reduces the cost of the fluid.

1. What type of heat exchanger is diagrammed below?
Shell and tube

Label the direction of fluid flow through the piping and shell.



- a. In solar air systems, centrifugal blowers are often used instead of conventional warm air heating blowers because of (increased, decreased) resistance in solar systems.
- b. Static pressure is: pressure inside an air filled container.
- c. Velocity pressure is: pressure required to accelerate air from a state of rest to the velocity observed.
- d. Total pressure is: sum of static and velocity pressures.
- e. For low pressure duct systems static pressure is usually specified for design purposes.
- f. As static pressure (increases, decreases) fan capacity decreases.
- g. The balance point of a system describes the air pressure and rate of air flow at which a fan operates most efficiently. It is identified by the point at which the fan curve crosses the system curve.
- h. A fan is operating at 400 rpm, delivering 1200 cfm at .20 in WG external static pressure, and requiring a brake horsepower (BHP) of .06. The fan speed is changed to 800 rpm. What is the new

air flow rate:

resistance pressure:

brake horsepower:

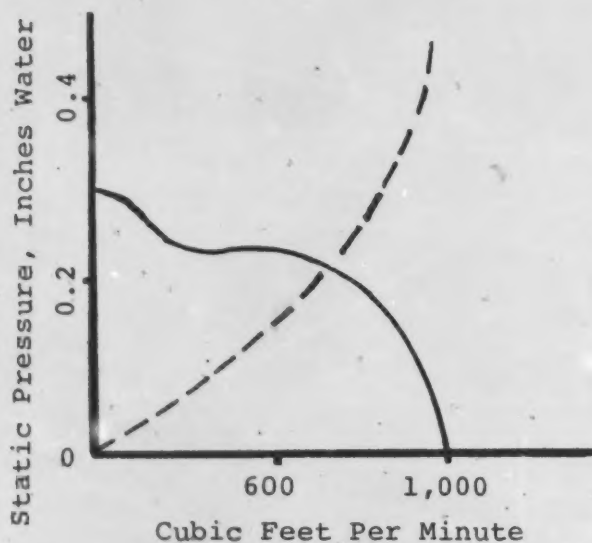
$$\begin{aligned}\text{New air flow rate (CFM)} &= \text{old CFM (new RPM/old RPM)} \\ &= 1200 (800/400) \\ &= 2400 \text{ cfm}\end{aligned}$$

$$\begin{aligned}\text{New resistance pressure (SP)} &= \text{old SP (new RPM/old RPM)}^2 \\ &= 0.20 (800/400)^2 \\ &= 0.40 \text{ in. WG}\end{aligned}$$

$$\begin{aligned}\text{New brake horsepower (BHP)} &= \text{old BHP (new RPM/old RPM)}^3 \\ &= 0.06 (800/400)^3 \\ &= 0.48\end{aligned}$$

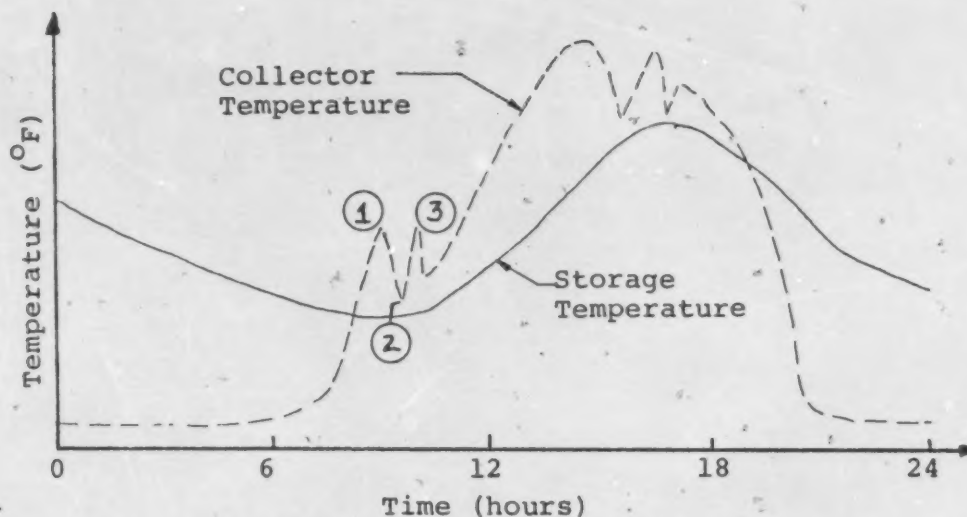
- i. The resistance pressure of a fan (increases, decreases) with rising air flow rate.

- j. The resistance of a duct system (increases, decreases) with rising air flow rate.
- k. List factors that can change the duct system curve.
dirt on a filter
damper adjustment
addition of more resistance
- l. Where is the fan balance point in the diagram shown below?
Circle it, and describe it in words.



- a. The three basic components of a controller are the sensor subsystem, the comparator subsystem and the output subsystem.
- b. The sensor subsystem measures temperatures.
- c. The comparator subsystem looks at temperature differences.
- d. The output subsystem turns on or off blowers, pumps, valves, or dampers.
- e. The decision to turn on or off an output device is based on temperature differences.
- f. In a space heating system, sensors are installed the following three locations: collector, storage tank, house.
- g. A temperature difference of about 3 degrees F, usually turns the collector/storage pumps.
- h. The collector/storage pumps usually turn on when the collector temperature exceeds the storage temperature by about 20 degrees F.
- i. Three types of sensors used in solar systems are thermistors, thermocouples, and transistor.
- j. What is done to avoid on-off pump cycling, and consequent excessive wear on the pump?
 Place the collector sensor near the collector outlet.
 Set the ratio between the on to off temperature differences at approximately five to seven.
- k. Turning on pumps to circulate water might be used to avoid freezing. Why is this not recommended?
 Electrical power to activate the pumps is sometimes unavailable when freezing may occur.

1. Consider the following figure: (similar to Figure 11-3)



The solid line represents storage temperature. The dashed line represents collector temperature. Describe completely what happened to the temperatures and in the control system at points 1, 2 and 3.

- Point 1. The collector-storage temperature difference was less than a predetermined amount (3°F), causing the collector storage pumps to go off.
- Point 2. The collector temperature exceeded the storage temperature by a predetermined amount (20°F) causing the collector/storage pumps to turn on.
- Point 3. Same as Point 1.

- a. The first stage of a two-stage thermostat calls for solar heat, while the second stage turns on the conventional heating system.
- b. A differential temperature controller measures difference between temperatures at two locations.
- c. A proportional differential controller varies pump speed as a function of the size of the temperature difference between collector and storage tank.
- d. A transducer converts changes in pressure or temperature into electrical or mechanical action.
- e. A bimetal sensor consists of metal strips which expand and bend at different rates per degree rise in temperature.
bellows/
- f. A diaphragm sensor contains a fluid which expands when heated to turn on the output mechanism.
- g. Electrical current flow varies in proportion to temperature in a sensor called a thermistor. The current change can be used to power other devices.
- h. Thermistor sensors can be located far from the controlled device.
- i. The ability of a sensor to react to temperature change is called the temperature coefficient.
- j. To detect collector overheating, a sensor is placed near the collector outlet.
- k. Two reasons for placing a thermistor in a bulb well in a liquid system are:
 1. to avoid sensor corrosion
 2. to allow servicing of the sensor without draining the system
- l. In liquid systems, valves are used to start, stop, and divert fluid flow.
- m. A transformer converts live voltage to lower voltage- Typically, solar control devices operate at 24 volts.
- n. In air systems, dampers are used to start, stop, and divert fluid flow.
- o. A low voltage thermostat is often used to activate a relay, causing a higher voltage output device to operate.

UNIT SB-5
DEMONSTRATION (C-2)

The instructor will show to students a variety of control devices available in the lab. The name, location, and function of each device should be identified. If possible, control device operation should be observed.

- a. Indicate the purpose and location of each of the following hydronics specialty items.

	<u>Location</u>	<u>Purpose</u>
expansion tank	near storage tank	allows room for expansion of heated water
air vent	above collector array	vents air from system as it's being filled
check valve	in connective piping	limits fluid flow to one direction
vacuum breaker	in connective piping	relieves an unwanted vacuum
pressure relief valve	in connective piping	prevents excessive pressure build-up
balancing valve	in connective piping	adjusts flow rates
pressure reducing valve	in input piping from regular water system	reduces water pressure
air eliminator	near storage tank	helps eliminate unwanted air
dielectric union	in connective piping	minimizes corrosion of connective fittings

- b. When must collector loop filling be done manually?

if local building codes prohibit connection of a solar system containing a toxic fluid to city water service.

"Instructor's Materials"

UNIT SB-5
DEMONSTRATION (C-4) 1

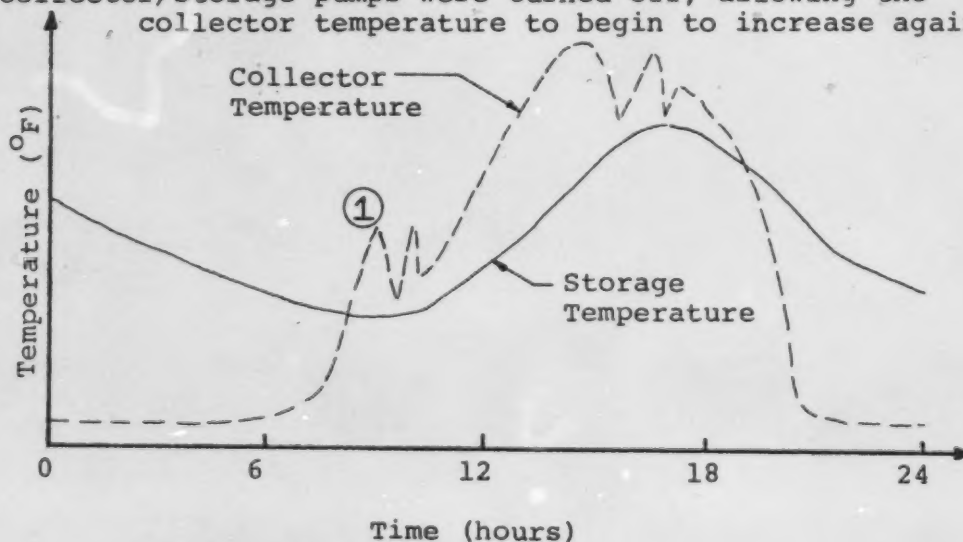
The instructor will show to student a variety of hydronic speciality devices. The name, location, and function of each device should be identified.

1. Circle T or F to indicate whether each of the following statements is true (T) or false (F). (3 1/3 points each.)
 - a. (T) F Larger pumps are required in open loop systems as compared to closed loop systems of comparable size.
 - b. T (F) One-speed pumps are as effective as two-speed pumps.
 - c. (T) F Static pressure is the type of pressure measured in automobile tires.
 - d. T (F) In low pressure systems, velocity pressure is most often used as a design standard for moving air.
 - e. T (F) A differential thermostat measures the temperature in one place.
 - f. T (F) A thermistor operates as a function of the difference in expansion of two metals.
 - g. (T) F Corrosion affects the sensitivity of a thermistor.
 - h. T (F) Liquid collector loops must be filled manually.
 - i. (T) F As static pressure increases, pump capacity decreases.
 - j. (T) F Solar control devices operate at a lower voltage than other hardware appliances.
2. Fill in the most correct answer. (3 1/3 points each correct answer.)
 - a. Pump capacity is given in pounds per square inch .
 - b. The most common type of heat exchanger used between collector and storage is called the shell & tube heat exchanger.
 - c. Three types of pressures that apply to air movement are static, velocity, and total pressure.
 - d. An air system should operate at the point where the duct system and fan curves intersect.
 - e. The point at which an air system should operate is called the balance point.

- f. The first stage of a two-stage thermostat calls for heat from the solar system.
- g. To reduce corrosion among dissimilar metal piping and components, they are connected by dielectric unions.
- h. The kind of pump most widely used in solar systems is the centrifugal pump.
- i. Pumps in open loops should be made of bronze or stainless steel to minimize corrosion.
- j. In a space heating system, temperatures sensors are installed in three locations: collector, storage, and room space.
- k. A temperature difference of about 20 degrees Fahrenheit usually turns on the collector/storage pumps.
- l. A check valve limits fluid flow to one direction.
- m. A pressure relief valve prevents excessive pressure build-up.

3. Describe what happened in the control system at Point 1, indicated below. (6 2/3 points.)

The sensors indicated that the collector temperature was decreasing to a point where it had approached the storage temperature by a predetermined amount (about 3° F). The collector/storage pumps were turned off, allowing the collector temperature to begin to increase again.



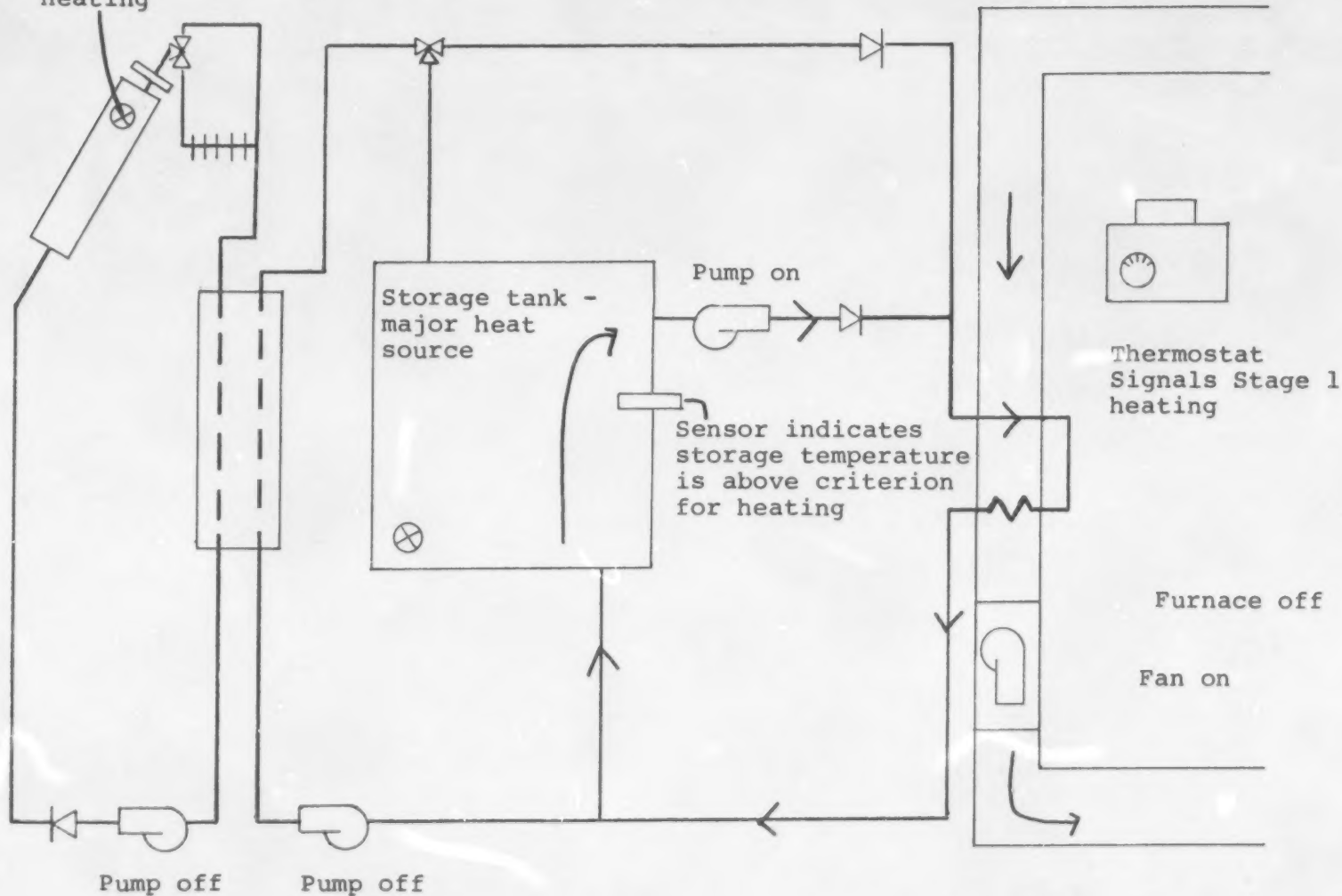
Sensor indicates that collector outlet temperature is adequate for heating

Diverting Valve
set so flow is to
heat coil



Mode of Operation: Heating from Storage

Sensor indicates that outlet temperature is inadequate for heating

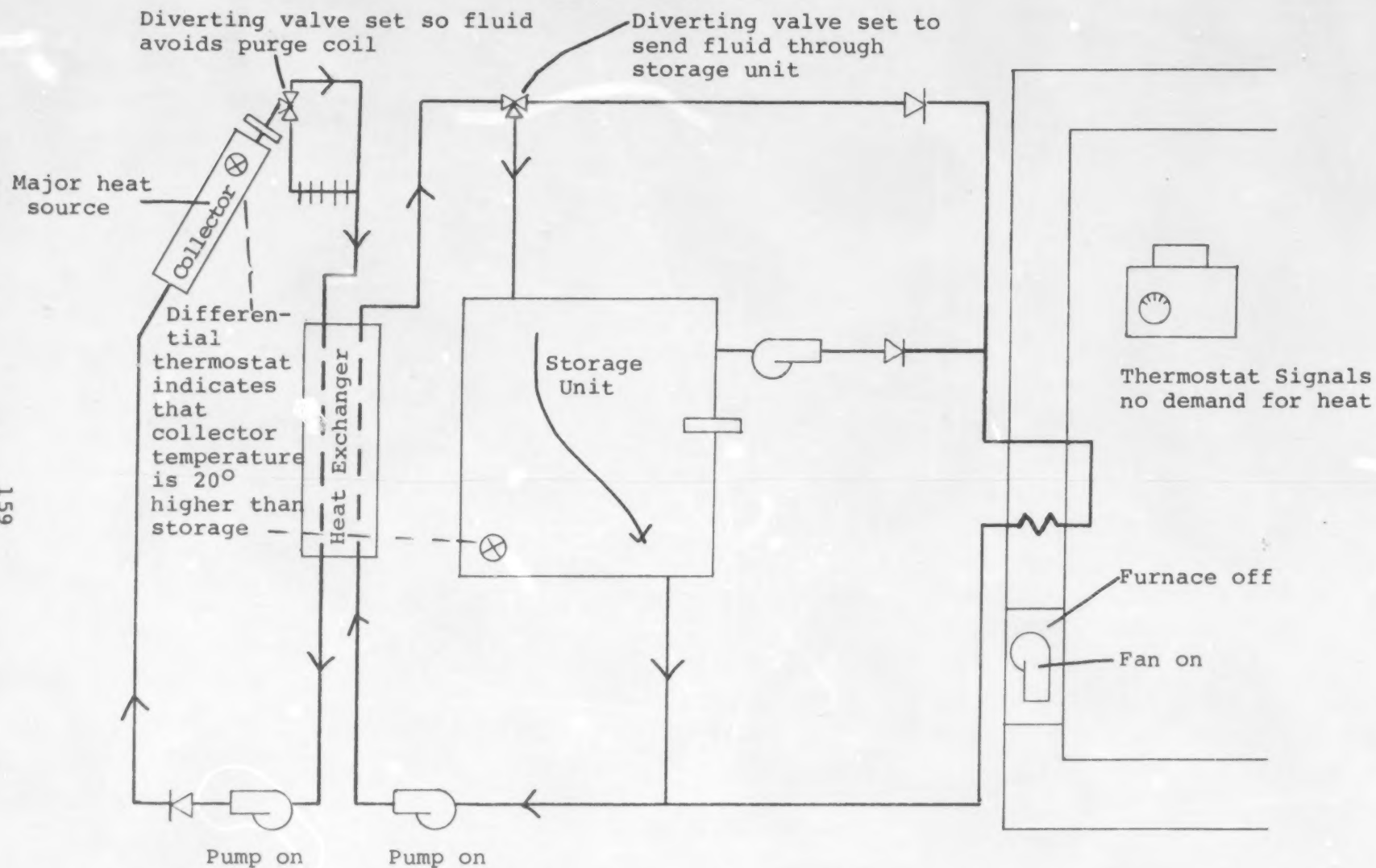


158

(160

160

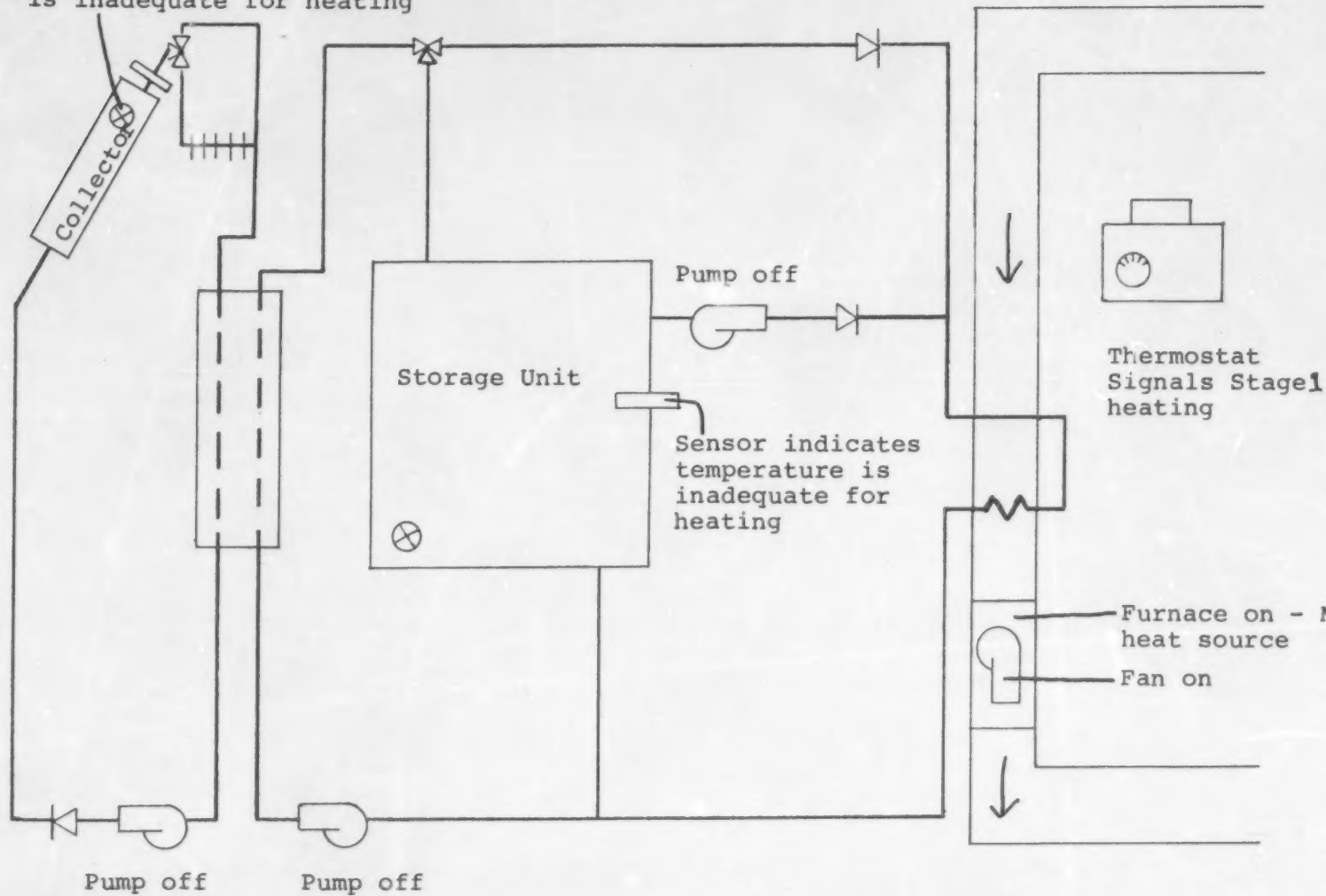
Mode of Operation: Storing Heat



159

Mode of Operation: Heating from Auxiliary Unit

Sensor indicates temperature is inadequate for heating



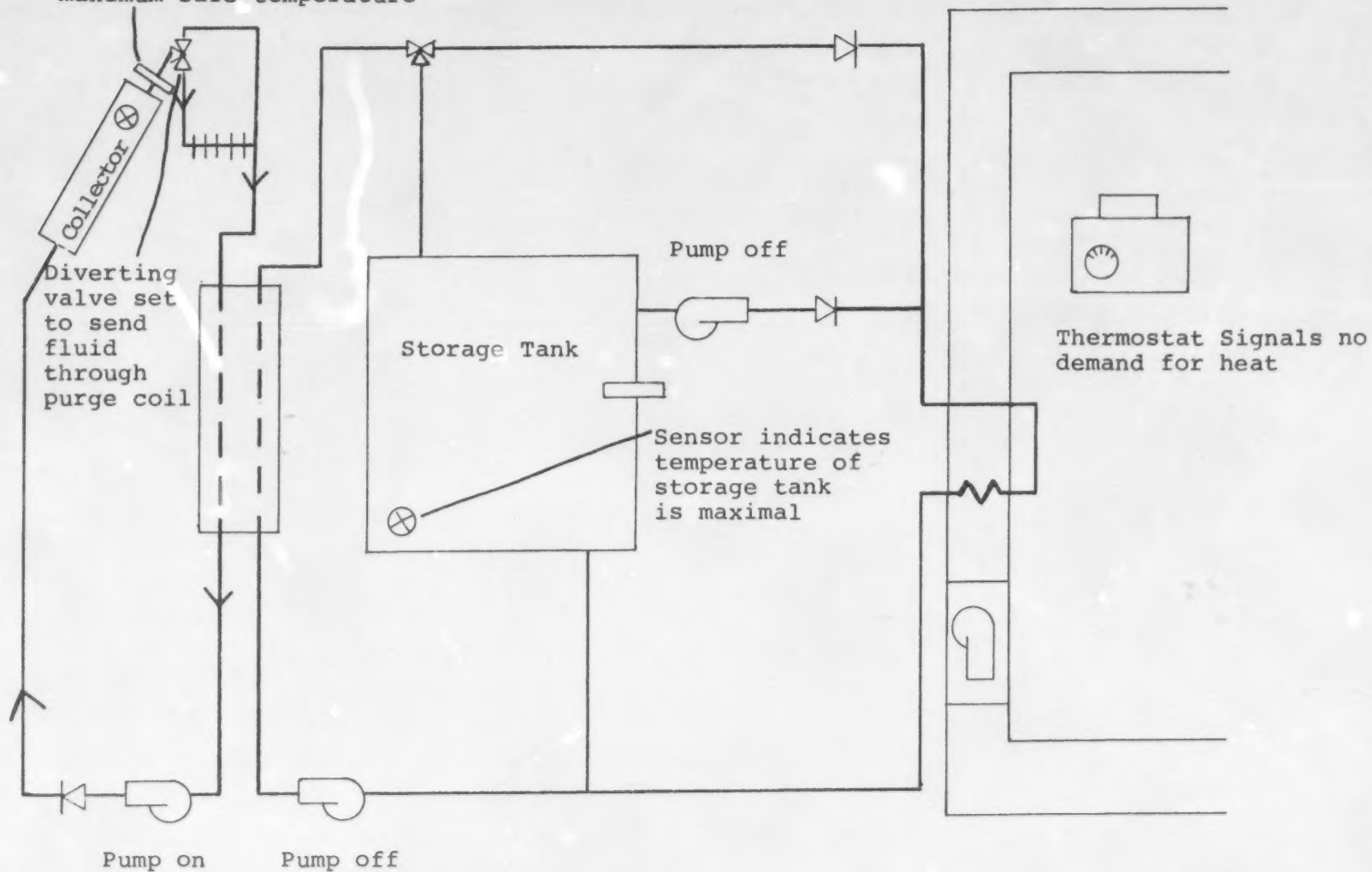
160

160

170

Mode of Operation: Purging heat

Aquastat indicates collector temperature has reached maximum safe temperature



161

LIQUID SYSTEM OPERATION

- a. What is the consequence for system operation of not being able to provide space heating directly from the collector?

Collectors must operate above storage tank temperature and thus, at higher inlet temperatures. Collector efficiency is reduced.

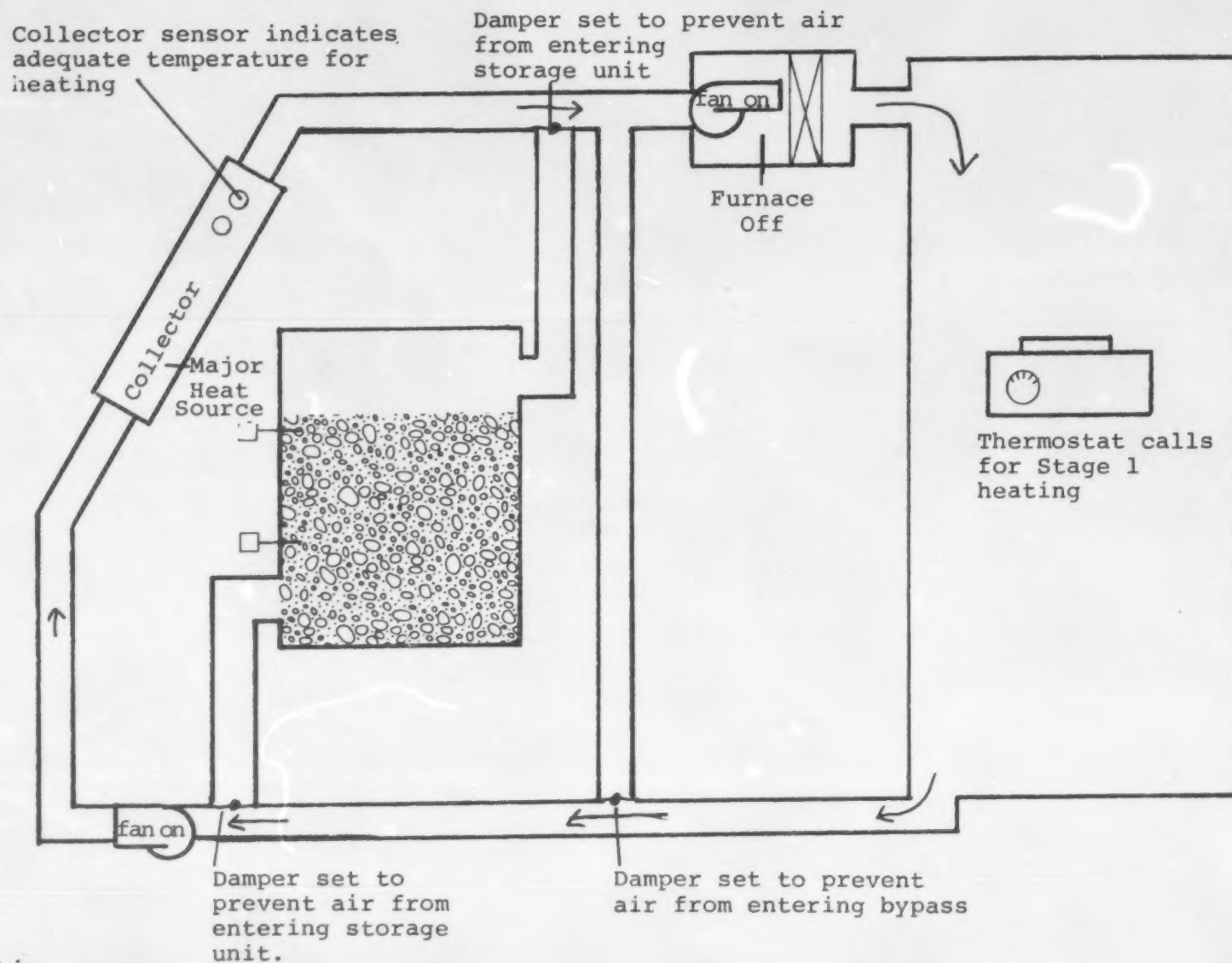
- b. How is the temperature of the solar heated liquid used for space heating related to the type of space heating system that can be used?

Some space heating systems require a higher temperature liquid than others. Hydronic baseboard units require 220° F water, usually available in systems where collectors do not provide direct space heating, and therefore must operate at higher temperatures in the range of 220° F. Radiant floor panels require only 110° F, and can be used where collectors operate at lower temperatures.

- c. If a heat pump is to be used for auxiliary heating, where should its refrigerant coil be placed relative to the duct coil?

The heat pump refrigerant coil should be after the duct coil in the flow of air.

Mode of Operation: Heating from Collectors



Mode of Operation: Heating from storage

Sensor indicates that temperature in collector is inadequate for heat

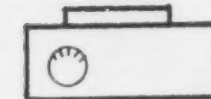
Damper set to direct air toward space

fan on

Furnace Off

Sensor indicates temperature is adequate for heating

Storage tank major heat source



Thermostat demands Stage 1 heating

fan off

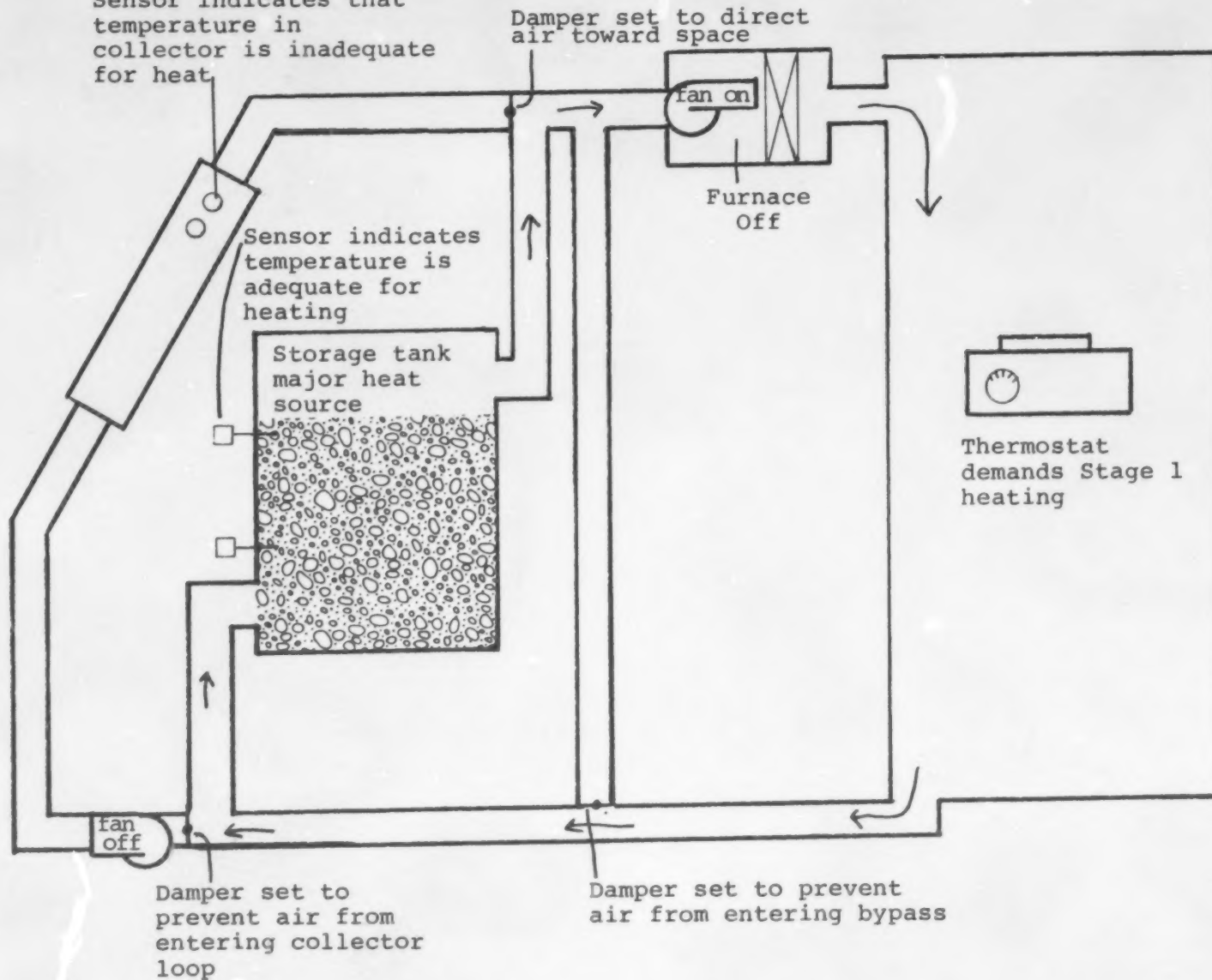
Damper set to prevent air from entering collector loop

Damper set to prevent air from entering bypass

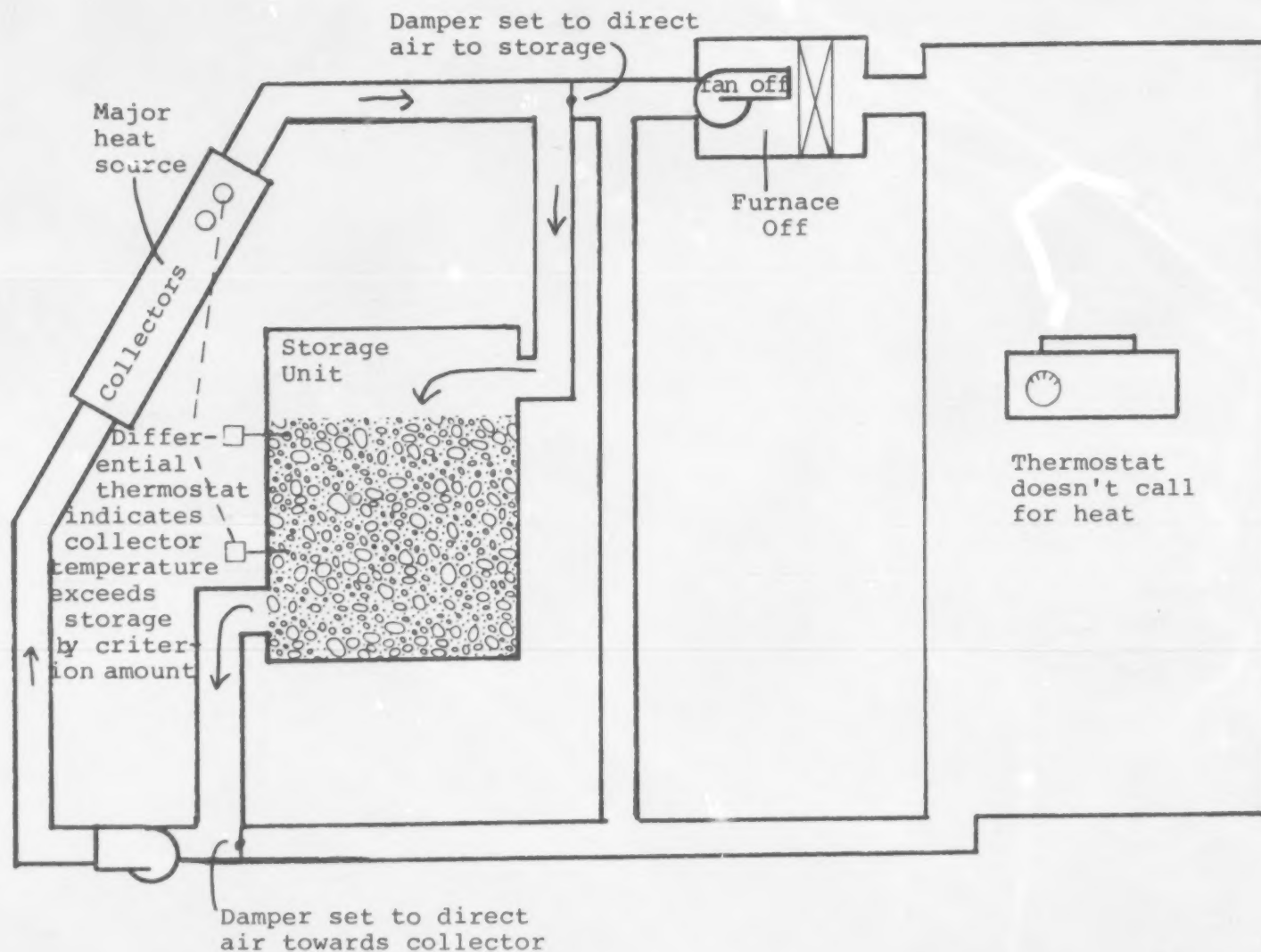
164

176

177



Mode of Operation: Storing heat



165

Mode of Operation: Heating from Auxiliary Unit

Collector sensor indicates temperature is below control point

Damper set to direct air through furnace

Storage sensor indicates temperature is below control point

Storage Unit

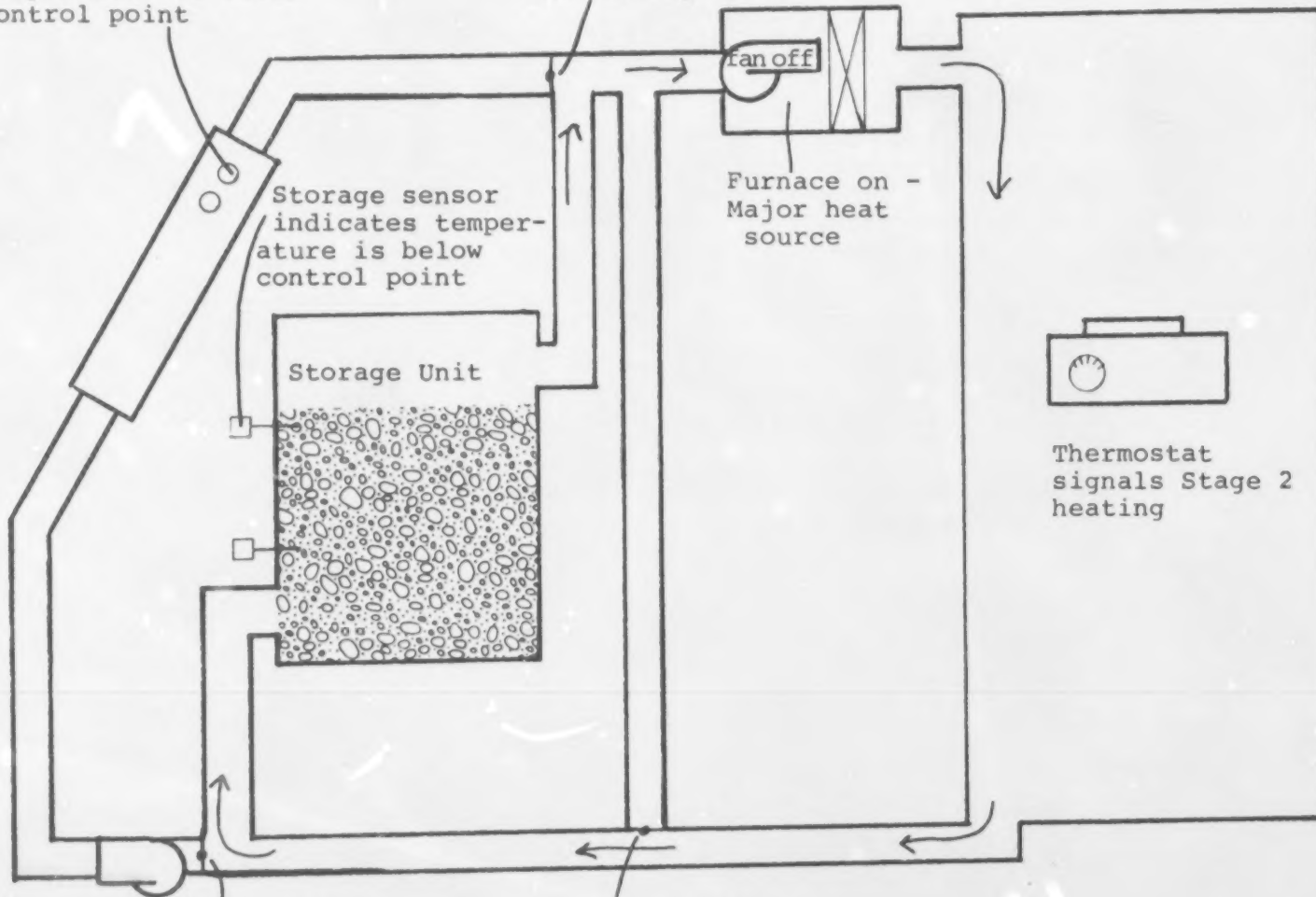
fan off

Furnace on - Major heat source

Thermostat signals Stage 2 heating

Damper set to direct air through storage

Damper set to avoid air flow through bypass



NARRATION SCRIPT

OPERATION OF LIQUID SOLAR HEATING SYSTEMS

SLIDE #1 (VMC TITLE SLIDE)

(Music up for about five to ten seconds ... then down under next frame's narration)

SLIDE #2 (Title: OPERATION OF LIQUID SOLAR HEATING SYSTEMS

We will now consider the different ways in which solar systems can operate to provide space heat.

SLIDE #3 (SYSTEM SCHEMATIC DRAWING)

Let us consider the operation of a solar liquid system. A representative system might look like this. Note that this system is only representative - other liquid systems differ somewhat from this one.

SLIDE #4 (SYSTEM DRAWING: COLLECTORS & STORAGE TANK HIGHLIGHTED)

The system includes liquid collectors to generate heat from solar radiation, and a liquid storage tank to store that heat.

SLIDE #5 (HEAT EXCHANGER & HEAT COIL HIGHLIGHTED)

Two heat exchangers are included. One, a liquid to liquid heat exchanger, transfers heat between the collector and storage loops. The other heat exchanger, a duct coil, transfers heat from the liquid in the storage loop to the air used for space heating.

SLIDE #6 (SYSTEM DRAWING: PUMPS & VALVES HIGHLIGHTED)

Liquid pumps are used to drive the liquid through the piping in the systems. Valves direct and redirect the liquid flow.

SLIDE #7 (SYSTEM DRAWING: PURGE COIL HIGHLIGHTED)

To prevent overheating, a purge coil is included in the collector loop. Overheated fluid is directed through the purge coil, which purges the heat to external air.

SLIDE #8 (SYSTEM DRAWING: FURNACE & BLOWER HIGHLIGHTED)

An auxiliary heating unit is included to boost the temperature of the air for space heating, if the solar heat is insufficient. This unit includes a blower which can be used to circulate air past the duct coil and through the ducts.

SLIDE #9 (SYSTEM DRAWING: SENSORS & THERMOSTAT HIGHLIGHTED)

Temperature sensors are included in the collector outlet, in the storage unit and in the space to be heated. The temperature sensors will be critical in determining the appropriate mode of operation.

SLIDE #10 (LIST OF MODES OF OPERATION)

A liquid system such as this has several basic operating modes. We will examine each in turn. For space heating, the modes of operation include: first, heating from the collector, second, heating from storage, and third, heating from the auxiliary unit.

SLIDE #11 (DRAWING OF THERMOSTAT)

Need for space heat is signalled by a two stage thermostat installed in the house. When house temperature falls below a predetermined level, the first stage of the thermostat initiates heating from the solar system. If the solar system alone is unable to supply adequate heat, the second stage of the thermostat initiates the back-up heating system to aid the solar system. If the solar system cannot provide any heat, the first stage of the thermostat turns on the auxiliary furnace.

SLIDE #12(SYSTEM SCHEMATIC DRAWING WITH HEATING FROM COLLECTORS
HIGHLIGHTED)

One mode of operation is heating from the collectors.

SLIDE #13 (HEATING FROM COLLECTORS: SENSORS HIGHLIGHTED)

This occurs when the room temperature falls below the temperature initiating Stage 1 heating, and the collector temperature sensor indicates that the collector liquid can provide heat. Typically, the collector outlet temperature must be 90° or higher.

SLIDE #14 (HEATING FROM COLLECTORS: HEAT EXCHANGER
HIGHLIGHTED)

In the system described, heating from the collectors must be described as "indirect" heating. The heat from the collectors does not directly heat the room air. Rather, the heat from the collectors is transferred to the liquid in the storage loop, and this liquid heats the room air.

SLIDE #15 (HEATING FROM COLLECTORS: COLLECTOR AND STORAGE
PUMPS HIGHLIGHTED)

Note the operation of the two pumps. The collector pump drives the liquid through the collector loop. The storage pump drives the liquid through the storage loop. The load pump is off.

SLIDE #16 (HEATING FROM COLLECTORS: VALVES HIGHLIGHTED)

The valves are set to allow liquid circulation through the collector loop, and through the loop around the storage tank. Liquid is not allowed to circulate through the storage tank in this mode of operation.

SLIDE #17 (HEATING FROM COLLECTORS: AUXILIARY HEATING UNIT
BLOWER HIGHLIGHTED)

The auxiliary heating unit blower is on to circulate air over the heat exchanger from the hot liquid loop. The unit is not heating the air, but is only circulating it.

SLIDE #18 (SYSTEM DRAWING WITH HEATING FROM COLLECTORS
HIGHLIGHTED)

This mode of operation is likely to occur on sunny, but cool days, when there is a need for house heating, and solar insolation alone can provide a lot of heat.

SLIDE #19 (SYSTEM DRAWING WITH HEATING FROM STORAGE HIGHLIGHTED)

The second possible operating mode for space heating is heating from storage.

SLIDE #20 (HEATING FROM STORAGE: THERMOSTAT & COLLECTOR SENSOR
HIGHLIGHTED)

This occurs when the room temperature sensors initiates Stage 1 heating, and the collector temperature, but not the upper storage temperature, is below a critical value. For example, the collector temperature might be below 90° F, but the upper storage temperature is above that point, indicating that the storage unit can provide heat.

SLIDE #21 (HEATING FROM STORAGE: LOAD LOOP PUMP HIGHLIGHTED)

Both storage and collector pumps are stopped, and the load pump is started to take heat from storage and circulate it through the air duct coil.

SLIDE #22 (HEATING FROM STORAGE: STORAGE TANK HIGHLIGHTED)

Note that the liquid is circulated from the bottom of the storage tank to the top. The cooled liquid first gathers heat from the lower layers of the tank liquid, further cooling them.

SLIDE #23 (HEATING FROM STORAGE: FLUID FLOW THROUGH HEAT EXCHANGER HIGHLIGHTED)

This contributes to the efficiency of the collector-storage loop heat exchanger. Recall that this heat exchanger draws liquid from the bottom of the storage tank. The cooler this liquid is, the more efficiently the heat exchanger works.

SLIDE #24 (HEATING FROM STORAGE: AUXILIARY UNIT HIGHLIGHTED)

In drawing space heat from storage, again the auxiliary unit fan is on to circulate air over the duct coil. The unit itself is not heating the air.

SLIDE #25 (SYSTEM DRAWING WITH HEATING FROM STORAGE HIGHLIGHTED)

This mode of space heating is likely to occur at night after a sunny day. The outdoor temperature is cool, and a considerable amount of heat has been stored during the day. Solar insolation can no longer provide heat, though it contributed to heating and to heat storage earlier in the day.

SLIDE #26 (DRAWING OF THERMOSTAT WITH STAGE TWO HIGHLIGHTED)

Sometimes neither the collectors nor the storage unit can provide enough heat for boosting room temperature. When there is a demand for space heat, and the solar system is unable to provide enough heat, the second state of the thermostat initiates auxiliary heating to provide additional heat.

SLIDE #27 (SYSTEM WITH HEATING FROM AUXILIARY HIGHLIGHTED)

In this case auxiliary unit both circulates and heats the air in the duct system.

SLIDE #28 (DRAWING SHOWING THREE MODES OF SPACE HEATING)

These, then, are the three modes of solar system operation for space heating:

heating from the collectors
heating from the storage unit,
and, auxiliary heating.

SLIDE #29 (SYSTEM WITH STORING HEAT MODE HIGHLIGHTED)

There are, however, two other important modes of operation. The first of these is storing heat.

SLIDE #30 (STORING HEAT: DIFFERENTIAL CONTROLLER HIGHLIGHTED)

Heat storage occurs when there is no demand for space heat. The temperatures at the collector outlet and lower storage tank are compared by a differential controller. If this comparison indicates that the collectors are considerably hotter than the storage tank, perhaps by 20° F, then heat storage can begin.

SLIDE #31 (STORING HEAT: HEAT EXCHANGER HIGHLIGHTED)

Both the collector pump and storage pump are turned on. This circulates the collector and storage liquids in opposite directions through the counter flow heat exchanger.

SLIDE #32 (STORING HEAT: DIVERTING VALVE HIGHLIGHTED)

The diverting valve is set to circulate the liquid through the storage tank, rather than through the duct coil.

SLIDE #33 (STORING HEAT: STORAGE UNIT HIGHLIGHTED)

Note that this time the heated liquid is circulated from the top of the tank to the bottom. The upper layers of the tank absorb as much heat as is possible before the lower, cooler layers are heated. This again allows the coolest liquid in the tank to be drawn back to the heat exchanger for reheating.

SLIDE #34 (SYSTEM WITH STORING HEAT MODE HIGHLIGHTED)

Heat storage is likely to occur on sunny, warm days, when the collectors are receiving much insolation, but little house heating is required.

SLIDE #35 (SYSTEM WITH HEAT PURGING HIGHLIGHTED)

A final mode of operation is the heat purge cycle. This is one method for getting rid of unusable heat, and preventing overheating. There are other methods that can be used for the same purpose, making a purge cycle unnecessary.

SLIDE #36 (PURGING HEAT: PURGE AQUASTAT HIGHLIGHTED)

If a system includes a purge cycle, the cycle is initiated when the collector temperature sensors indicate that the collectors are in danger of overheating. Sensor in the storage tank indicate that the tank can't store any more heat. There is also no need for space heating.

SLIDE #37 (PURGING HEAT: COLLECTOR PUMP HIGHLIGHTED)

Only the collector pump is operating. Both the storage and load pumps are off.

SLIDE #38 (PURGING HEAT: DIVERTING VALVE HIGHLIGHTED)

A diverting valve diverts the collector liquid through the purge coil. The purge coil dissipates unwanted heat into the outside air.

SLIDE #39 (PURGING HEAT: SYSTEM WITH HEATING PURGING HIGHLIGHTED)

The purge cycle is likely to occur toward the end of a sunny warm day. Maximum amounts of heat have been stored, and there is no need for solar heating.

SLIDE #40 (SOLAR SYSTEM SCHEMATIC DRAWING)

We have now seen the five different modes of a representative solar space heating system. To review, the five modes are:

SLIDE #41 (SYSTEM WITH HEATING FROM COLLECTORS HIGHLIGHTED)

Heating from collectors

SLIDE #42 (SYSTEM WITH HEATING FROM STORAGE HIGHLIGHTED)

Heating from storage.

SLIDE #43 (SYSTEM WITH AUXILIARY HEATING HIGHLIGHTED)

Auxiliary heating.

SLIDE #44 (SYSTEM WITH STORING HEAT HIGHLIGHTED)

Storing heat.

SLIDE #45 (SYSTEM WITH PURGING HEAT HIGHLIGHTED)

and, purging heat.

CALCULATING R_T , U

Problem 1

A solid masonry wall consists of the following layers, having the resistances listed.

	<u>R</u>
Outside air film (15 mph wind, winter)	.17
Face brick (2-inch)	.22
Common brick (4-inch)	.80
Air space (4-inch, non-reflective)	1.01
Gypsum board ($\frac{1}{2}$ -inch)	.45
Inside air film	<u>.68</u>

$$R_T = 3.33$$

What is the U value of the wall? Show the calculations below.

$$U = \frac{1}{R_T}$$

$$U = \frac{1}{3.33} = 0.30 \text{ Btu/hr/ft}^2/\text{°F}$$

Problem 2

Calculate the R value for the following materials. (Remember that $R = l/k \times$ (thickness of material).)

- a. stucco (4 inches thick)

$$R = 0.20 \times 4 = 0.8$$

b. gypsum board ($\frac{1}{2}$ -inch thick)

$$R = 0.90 \times \frac{1}{2} = 0.45$$

c. common brick (5-inches thick)

$$R = 0.20 \times 5 = 1.0$$

d. insulation (2-inches thick)

$$R = 3.58 \times 2 = 7.16$$

Problem 3

Consider the wall diagramed below.

	R	
air film	0.17	
siding	0.87	
sheathing	1.32	$R = 2.63 \times \frac{1}{2} = 1.32$
insulation	22.00	
gypsum board	0.90	$R = 0.90 \times 1 = 0.90$
air film	<u>0.68</u>	

a. Calculate R_T .

$$R_T = 25.94$$

b. Calculate U.

$$U = \frac{1}{R_T}$$

$$U = \frac{1}{25.94} = 0.04 \text{ Btu/hr/ft}^2/\text{°F}$$

Problem 4

A floor consists of the following layers.

$$R = 1.24 \times 3/4 = 0.93 \leftarrow$$

	R
carpet and rubber pad	1.23
plywood (3/4-inch)	0.93
insulation (6-inch)	22.00
surface (still air-non-reflective-heat flow up)	0.61
	R_T 24.77

What is the U value of the floor? Show the calculations below.

$$U = \frac{1}{R_T}$$

$$U = \frac{1}{24.77} = 0.04$$

- 1) Calculate U for the wall with layers indicated below:

	R
Outside air film (winter)	.17
Face brick (4-inch)	.44
Common brick (4-inch)	.44
Air space (3/4-inch, non-reflective)	1.28
Gypsum board (1/2-inch)	.45
Inside surface	.68

$$R^T = 3.46$$

$$U = \frac{1}{R^T} = \frac{1}{3.46} = 0.29$$

- 2) Calculate R for the following materials:

- a. Common brick (3-inch): $1/k = .20$

$$R = \frac{1}{K} \times \text{thickness}$$

$$R = 0.2 \times 3 = 0.6$$

- b. Gypsum board (1-inch): $1/k = .90$

$$R = 1 \times 0.90 = 0.90$$

- c. Softwood board (1/2-inch): $1/k = 1.25$

$$R = 1.25 \times \frac{1}{2} = 0.63$$

- 3) The U value of a material describes:

The number of Btu's that will pass through one square foot of a material of known thickness in one hour, given a temperature difference of 1°F .

USING DESIGN & DEGREE DAY DATA

- a. Indicate the winter design temperature for:

Los Angeles, California	<u>42° F</u>
Dubuque, Iowa	<u>-11° F</u>
Jacksonville, Florida	<u>29° F</u>

- b. Indicate the annual degree days and degree days in January for each of the following locations:

	<u>January</u>	<u>Annual</u>
Rome, Georgia	710	3326
Chicago, Illinois	1209	6155
New Haven, Connecticut	1097	5897

- c. For each of the pairs of locations listed below, circle the location which is colder in December.

(Columbus, Georgia) or Orlando, Florida

San Francisco, California or (Sacramento, California)

(San Diego, California) or Tampa, Florida

- d. Indicated below are the average daily temperatures on January 20 for three different locations. Calculate the number of degree days for each location.

	<u>Average Temperature on January 20</u>	<u>Degree Days</u>
Buffalo, New York	20° F	45°
Atlanta, Georgia	32° F	33°
Miami, Florida	47° F	18°

Problem 2

The house is built on a concrete slab on grade with 1" x 12" insulation. What is the rate of winter heat loss from the slab?

$$\begin{aligned}\text{Rate of heat loss} &= UA (T_R - T_O) \\ U &= 0.46 \text{ Btu/hr/ft}^2/\text{°F} \\ A &= 30 \text{ ft} \times 40 \text{ ft} = 1200 \text{ ft}^2 \\ T_R - T_O &= 65^\circ - 18^\circ = 47^\circ \\ \text{Rate of heat loss} &= 0.46 \text{ Btu/hr/ft}^2/\text{°F} (1200 \text{ ft}^2) (47^\circ) \\ &= 25,944 \text{ Btu/hr}\end{aligned}$$

Problem 3

What is the rate of heat loss due to infiltration in the winter?

$$\begin{aligned}h &= 0.018 \text{ B } (\Delta T) \\ \text{Volume of house} &= 30 \text{ ft} \times 40 \text{ ft} \times 14 \text{ ft} = 16,800 \text{ ft}^3 \\ \text{In a normal residence, volume flow rate is one per hour} \\ V &= 16,800 \text{ ft}^3/\text{hr} \\ \Delta T &= 65^\circ - 18^\circ = 47^\circ \\ h &= 0.018 (16,800 \text{ ft}^3/\text{hr}) (47^\circ) \\ h &= 14,212 \text{ Btu/hr}\end{aligned}$$

Problem 4

The ceiling of the house has a U value of .04. What is the rate of heat loss through the ceiling? (Note: Even though an attic may cover the ceiling, it is commonly assumed that the temperature of well-ventilated attic is about the same as the outdoor design temperature.)

$$\begin{aligned}\text{Rate of heat loss} &= UA (T_R - T_O) \\ U &= 0.04 \text{ Btu/hr/ft}^2/\text{°F} \\ A &= 40 \text{ ft} \times 30 \text{ ft} = 1200 \text{ ft}^2 \\ T_R - T_O &= 65^\circ - 18^\circ = 47^\circ \\ \text{Rate of heat loss} &= 0.04 \text{ Btu/hr/ft}^2/\text{°F} (1200 \text{ ft}^2) (47^\circ) \\ &= 2256 \text{ Btu/hr}\end{aligned}$$

Problem 5

What is the total rate of heating loss from the sources considered so far?

<u>Sources of heat loss</u>	<u>Rate of heat loss</u>
Walls	27,636 Btu/hr
Concrete slab	25,944
Infiltration	14,212
Ceiling	2,256
Total heat loss =	42,412 Btu/hr

Problem 6

What other sources of heat loss must be considered in calculating the total rate of heat loss for an ordinary house?

Heat loss through doors
windows

- 1) The small cottage is 15 x 20 feet in floor area, and has a 12 foot ceiling height. The winter design temperature for the area is 25° F, and the indoor design temperature is 65° F. For the walls, $U = .07$. For the ceiling, $U = .05$.

- a. What is the rate of heat loss through the walls?

$$\text{Wall area} = (20 \text{ ft} \times 12 \text{ ft} \times 2) + (15 \text{ ft} \times 12 \text{ ft} \times 2)$$

$$= 240 \text{ ft}^2 + 360 \text{ ft}^2 = 600 \text{ ft}^2$$

$$h = \mu A (T_R - T_O)$$

$$h = 0.07 \text{ Btu/hr/ft}^2/\text{°F} (600 \text{ ft}^2) (65^\circ - 25^\circ)$$

$$h = 1680 \text{ Btu/hr}$$

- b. What is the rate of heat loss through the ceiling?

$$\text{Ceiling area} = 15 \text{ ft} \times 20 \text{ ft} = 300 \text{ ft}^2$$

$$h = 0.05 \text{ Btu/hr/ft}^2/\text{°F} (300 \text{ ft}^2) (65^\circ - 25^\circ)$$

$$h = 600 \text{ Btu/hr}$$

- c. What is the total rate of heat loss?

$$600 \text{ Btu/hr} + 1080 \text{ Btu/hr} = 2280 \text{ Btu/hr}$$

CALCULATING SPACE HEATING LOAD

- a. A house in Atlanta, Georgia has a heat loss of 40,140 Btu/hr. Calculate the following:

Space heating load, Btu/DD: =

$$\frac{\text{Heat loss rate}}{\text{Design Temperature Difference}} \times 24 \text{ hr/day}$$

$$= \frac{40,140 \text{ Btu/hr}}{65^{\circ}-18^{\circ}} \times 24 \text{ hr/day} = 20,497 \text{ Btu/DD}$$

Monthly heating load, Btu (in February): =

Heat load/DD x number of DD

$$= 20,497 \text{ Btu/DD} \times 529 \text{ DD}$$

$$= 10,842,924 \text{ Btu or } 10.8 \text{ mBtu}$$

Annual heating load: =

Heat load/DD x annual number of DD

$$= 20,497 \text{ Btu/DD} \times 2983 \text{ DD}$$

$$= 61,142,551 \text{ Btu or } 61.1 \text{ mBtu}$$

A house in Rome, Georgia has a winter heat loss of 52,170 Btu/hr. The winter design temperature for Rome is 16° F.

- a. Calculate the space heating load per degree day.

$$\begin{aligned}\text{Space heating load, } \frac{\text{Btu}}{\text{DD}} &= \frac{\text{House heat loss rate}}{\text{Design temperature difference}} \times 24 \text{ hr/day} \\ &= \frac{52,170 \text{ Btu/hr}}{(65^{\circ} - 16^{\circ})} \times 24 \text{ hr/day} \\ &= 25,553 \text{ Btu/DD}\end{aligned}$$

- b. Calculate the monthly heat load in February. (DD=577)

$$\begin{aligned}\text{Space heating load} \times \text{number of DD in month} \\ &= 25,553 \text{ Btu/DD} \times 577 \text{ DD} \\ &= 14,743,879 \text{ Btu or } 14.7 \text{ MBtu}\end{aligned}$$

CALCULATING DHW LOAD

A household has five occupants. Calculate the heat load for:

a. Daily DHW heating =

$$\begin{aligned} & \text{Number of occupants} \times 16,680 \text{ Btu/person/day} \\ &= 5 \text{ persons} \times 16,680 \text{ Btu/person/day} \\ &= 83,400 \text{ Btu/day} \end{aligned}$$

b. Monthly DHW heating (May) =

$$\begin{aligned} & \text{Daily load} \times \text{Days in month} \\ &= 83,400 \text{ Btu/day} \times 31 \text{ days} \\ &= 2,585,400 \text{ Btu} \end{aligned}$$

c. Annual DHW heating =

$$\begin{aligned} & \text{Monthly load} \times 12 \text{ months} \\ &= 2,585,400 \text{ Btu/month} \times 12 \text{ months} \\ &= 31,024,800 \text{ Btu or } 31.0 \text{ mBtu} \end{aligned}$$

"Instructor's Materials"

UNIT SB-7
DEMONSTRATION (C-4)

The instructor should carefully review with students the problem presented on Information Sheet SB-7-7.

Building Heat Load Calculations

Job Solution for Prob. Number of Occupants 4
 Computed by _____ Date Jan 13, 1977
 Location Fort Collins, Colo. Latitude 40° N

Indoor temperature, T_R , 68 °F
 Design winter outdoor temperature, T_O , -9 °F
 Design temperature difference 77 °F
 Design degree-day, 65 - T_O , 72 °F

Building Dimensions:

Above Grade: Length 50.4 ft Width 27.6 ft Ceiling Height 8 ft (9.25) Hall
 Below Grade: Length _____ ft Width _____ ft Depth 7.67 ft
 Concrete Floor Slab: Exposed perimeter _____ ft

Exterior Wall Area: $8 \times (50.4 + 27.6) \times 2 - (26.25 \times 8) +$
 $(9.25 \times 9.67 \times 2) + \text{Garage-Hall } (9.25 \times 26.25) = 1460 \text{ ft}^2$

Window Area: $(1 \times 2.67 \times 2.92) + (2 \times 2.67 \times 3.58) +$
 $(2 \times 3.92 \times 4.42) + (4 \times 2.67 \times 3.53) + 6(1.75 \times 2.67) \text{ Basement.}$

Door Area: (6.75×5.48)
 $\text{Garage } (2 \times 6.67 \times 2.42) \text{ Patio } (6.67 \times 2.96) \times 2$

Net Exterior Wall Area: $1038 + 179 + 243 - 100 - 37 - 32 - 37 - 40$
1214 ft²

Ceiling Area: $(50.4 \times 27.6) + (9.67 \times 26.25)$ 1645 ft²

Floor Area: On Slab 46 ft exposed edge
Basement 50.4 x 27.6 1391 ft²

Basement Wall Area: $7.67 \times (50.4 + 27.6) \times 2 - 28$ 1169 ft²

Heating Degree-Days: January 1250 °F-days
 Annual 6300 °F-days

		$\frac{U \text{ Btu}}{(\text{hr})(\text{ft}^2)(^\circ\text{F})}$	A	$\Delta T \text{ } ^\circ\text{F}$ ($T_R - T_O$)	$h = UA \Delta T$ Btu/hr
Exterior Walls (net)		.08	1214	77	7478
Basement Walls	Above grade				
	Below grade	.06	1169	23 *	1613
Windows and Sliding Patio Doors	Single	1.13	26	77	2262
	Double	0.65	31	77	1551
	Triple				
	Storm	0.56	128	77	5519
Exterior Slab Doors		0.49	69	77	2603
Floors	Over Crawlspace				
	Concrete Slab on Grade	0.81	46	44	1639
	Basement	.06	1440	23	1987
Ceiling		.05	1645	77	6333
Subtotal (walls, windows, doors, floors, ceiling)					
Infiltration: (0.018) $\times \frac{50.4 \times 27.8 \times 8}{9.25 \times 26.25 \text{ ft}^3} \times 77 \text{ } ^\circ\text{F}$					18.790
Duct = 10% of subtotal (if ducts not in insulation envelope)					—
Design Heating Load: Btu/hr					49,775
Design Heating Load: Btu/DD Design Heating Load (Btu/hr) X (24 hr/Design TD)					15,514
January Heating Load: m Btu (Btu/DD) X (January DD)					19.4
Annual Heating Load: m Btu (Btu/DD) X (Annual DD)					97.7

* $\Delta T = T_R - 45^\circ$

DOMESTIC HOT WATER LOAD

Number of occupants X 16,680 Btu/day	66,720
January Load (m Btu) (Btu/day) x 31 x 10 ⁻⁶	2.1
Annual Load (m Btu) (January load x 12)	24.8

- 1) Calculate U for the wall described below:

	R
Outside surface	0.17
Face brick (4")	0.44
Concrete block (2 rectangular cores, 8" sand and gravel aggregate)	1.04
Air space (3", non-reflective)	0.87
Gypsum board ($\frac{1}{2}$ inch)	0.45
Inside surface (non-reflective)	0.68

$$R_T = 3.65$$

$$U = \frac{1}{R_T} = \frac{1}{3.65} = 0.27$$

- 2) Based on degree days, circle the colder of the two cities in March.

Athens, Georgia	or	(Atlanta, Georgia)
Columbus, Georgia	or	(Augusta, Georgia)
(Sioux City, Iowa)	or	Pocatello, Idaho

- 3) A house in Savannah, Georgia has an area of 40 ft by 50 ft, and has 12 ft ceilings.

- a. If the coefficient of heat transmission for the walls is .45, what is the winter rate of heat loss through the walls?

$$\text{Wall area} = (2 \times 40 \times 12) + (2 \times 50 \times 12) = 2160 \text{ ft}^2$$

$$h = UA (T_R - T_O)$$

$$h = 0.45 (2160) (65-24) = 39,852 \text{ Btu/hr}$$

- b. The house has two solid wood slab doors, each 1.50" thick with no storm door, with each having an area of 7 feet by 4 feet. What is the winter rate of heat loss through the doors?

$$\text{Door area} = 2 \times 7 \times 4 = 56 \text{ ft}^2$$

$$h = 0.49 (56) (65-24) = 1125 \text{ Btu/hr}$$

4. A house in Tampa, Florida has a heat loss rate of 32,000 Btu/hr.

- a. What is the space heating load per degree day?

$$\text{Space heating load, Btu/DD} = \frac{32,000}{65-24} \times 24 = 18,731 \text{ Btu/DD}$$

- b. What is the heating load in the month of March?

$$\text{March heating load} = 18,731 \text{ Btu/DD} \times 102 \text{ DD} = 1,910,634 \text{ Btu}$$

- c. What is the annual heating load?

$$\begin{aligned} \text{Annual heating load} &= 18,731 \text{ Btu/DD} \times 683 \text{ DD} = 12,793,273 \text{ Btu} \\ &\text{or } 12.8 \text{ MBtu} \end{aligned}$$

5. A house has four occupants.

- a. What is the daily hot water load?

$$4 \times 16,680 = 66,720 \text{ Btu/day}$$

- b. What is the hot water load in January?

$$66,720 \text{ Btu/day} \times 31 \text{ days} = 2,068,320 \text{ Btu}$$

6. Calculate the total heat load (space and water heating) for January for the house described below:

Location: Macon, Georgia

Construction:

	U	Total Area
Walls	.07	1920 ft ²
Windows	1.13	75 ft ²
Doors	.49	56 ft ²
Ceiling	.05	1500 ft ²
Floor	.17	1500 ft ²

Number of occupants: four

Answer to #6, page 2.

Rates of heat loss:

Walls: $.07(1920)(65-23) = 5644.8 \text{ Btu/hr}$

Windows: $1.13(75)(65-23) = 3559.5$

Doors: $.49(56)(65-23) = 1152.5$

Ceiling: $.05(1500)(65-23) = 3150.0$

Floor: $.17(1500)(65-23) = \underline{10710.0}$

24216.8 Btu/hr

Space heating Load, Btu/DD = $\frac{24216.8}{65-23} \times 24 = 13838.2 \text{ Btu/DD}$

January Space Heat Load = $13838.2 \times 505 = 6,988,276$

January Hot Water Load = $4 \times 16680 \times 31 = 2,068,320$

Total January Heat Load = $2,068,320 + 6,988,276 = 9,056,596 \text{ Btu or } \underline{\underline{9.1 \text{ mBtu}}}$

Answer the following study questions:

- a. You are installing a solar system using Fedders collectors in Atlanta, Georgia. You want the collectors to supply 14.0 mBtu during January. How many collectors are required?

$$\frac{14,000,000 \text{ Btu}}{423,800 \text{ Btu/collector}} = 33.0 \text{ collectors}$$

How many collectors are required to supply the same amount of heat in October?

$$\frac{14,000,000 \text{ Btu}}{566,300 \text{ Btu/collector}} = 24.7 \text{ or } 25 \text{ collectors}$$

Why is there a difference in the number of collectors required in July versus January?

Insolation is greater during October

- b. Use the LC divisor method to solve the following problem. You are designing a collector array for a house in Griffin, Georgia. The heat loss is 53,000 Btu per hour with a 22° F average outdoor temperature and a 68° F average indoor temperature. What collector area is required to supply 50% of the total heat?

$$\text{Btu/DD} = \frac{\text{Btu/hr}}{t_i - t_o} \times 24 \text{ hrs/day} =$$

$$\frac{53,000}{68-22} \times 24 = 27652.2 \text{ Btu/DD}$$

For a 50% solar contribution

$$\frac{\text{Btu/DD}}{\text{LC}} = \frac{27.652}{84} = 329.19 \text{ ft}^2$$

What area is required to supply 75% of total heat?

For a 75% solar contribution

$$\frac{27.652}{42} = 658.4 \text{ ft}^2$$

- c. Use the SMACNA procedure to choose an appropriate collector array size for the case described in problem b, with a liquid solar array supplying 50% of the heat. The collector tilt angle is 53° F.

$$\frac{53,000}{177} = 299.4 \text{ ft}^2$$

- d. Why do the SMACNA procedure and the LC divisor method estimate different collector array sizes?

SMACNA procedure allows for differences in tilt angle, and between types of collector (air versus liquid) which are not allowed for in the Los Alamos procedure.

Answer the study questions below.

- a. What are the two factors whose ratio is X?

$$X = \frac{\text{monthly collector losses}}{\text{monthly heating demand}}$$

- b. What are the two factors whose ratio is Y?

$$Y = \frac{\text{monthly solar energy absorbed}}{\text{monthly heating demand}}$$

- c. What does f represent?

f = fraction of heating demand supplied by collector

- d. For liquid solar systems, what fraction of monthly energy is supplied for systems having the following X and Y values?

Fraction of Monthly Energy Supplied

x = 9, y = 1.00	0.4
x = 12, y = 2.75	0.9
x = 2, y = .25	0.1

- e. Which of the above systems is probably most economical? Why? The system with X = 9, Y = 1.0 is probably most economical because solar system which provide 90% of the heating requirement are very expensive to buy & install. Those that provide only 10% are less expensive, but don't provide enough energy to justify their cost. Systems which supply about 50% of the necessary heat energy are moderate in price and make a significant contribution to heating.
- f. If you wanted to design a liquid system supplying 60% of the monthly energy, what would be one possible pair of X and Y values for your system?

$$X = 12, Y = 1.60$$

$$X = 10, Y = 1.25$$

Choose the coordinates of the points on the curve f = 0.60.

TILT ANGLE, ORIENTATION AND COLLECTOR EFFICIENCY

Answer the study questions below.

- a. What is the optimal collector tilt angle, relative to latitude, for:

space heating only	<u>Latitude + 15°</u>
space heating-cooling only	<u>Latitude + 5°</u>
domestic hot water heating only	<u>Latitude</u>

- b. Because of architectural restraints, a collector array for hot water heating in Griffin, Georgia (latitude 33°) must be tilted at 28°. At that angle, what will be the efficiency of the array, relative to maximal efficiency?

90%

- c. To what extent must the above array size be increased so that maximal array efficiency is achieved?

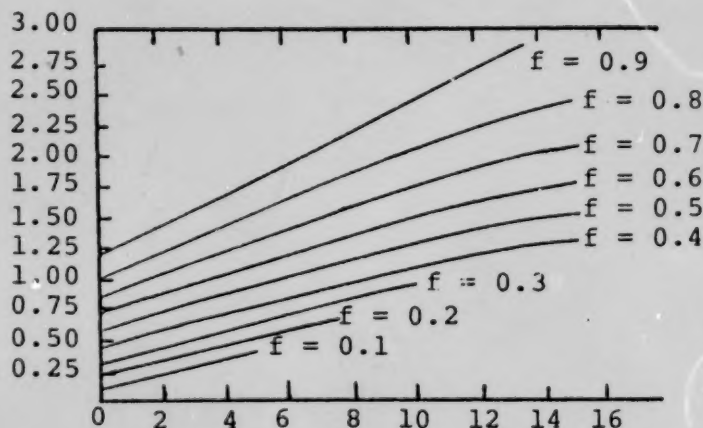
$$\frac{1}{0.90} - 1 = 11\% \text{ increase in size}$$

- d. Relative to optimum efficiency, what is the efficiency of a collector tilted 30° east of south? 96%

To what extent must array size be increased to compensate for this loss of efficiency?

$$\frac{1}{0.96} - 1 = 4\% \text{ increase in size}$$

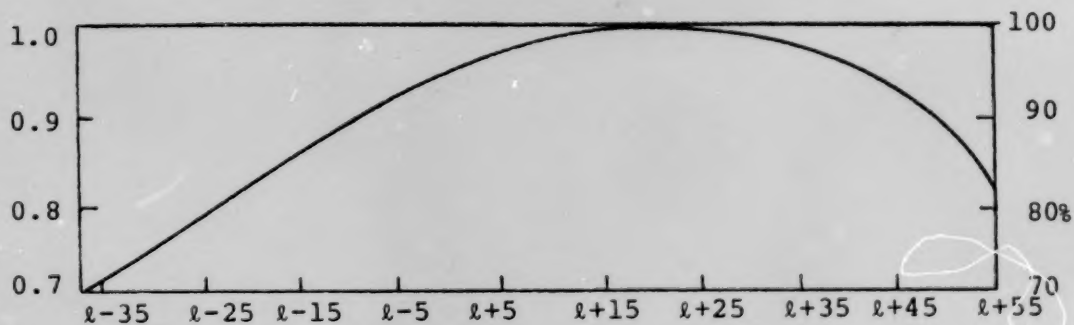
- 1) The first component of the solar system that should be sized is the collectors.
- 2) The rule of thumb for sizing collectors based on residence floor area is that the collector area should be 1/3 to 1/2 of the floor area.
- 3) A procedure of sizing collectors that distinguishes between air and liquid systems, and different tilt angles is the sizing procedure developed by SMACNA or Univ. of Wisconsin FCHART.
- 4) In the F-Chart method, "f" stands for the fraction of the monthly heating demand supplied by the solar system.
- 5) Using the graph below, determine f when $x = 10$, $y = 1.5$.
 $f = 0.6$



- 6) X represents $\frac{\text{monthly collector losses}}{\text{monthly absorbed}}$ divided by $\frac{\text{monthly heating demand}}{\text{monthly}}$
- 7) Y represents $\frac{\text{solar energy}}{\text{heating demand}}$ divided by $\frac{\text{monthly}}{\text{heating demand}}$.
- 8) Collector efficiency is a measure of the ability of a collector to absorb and transmit heat energy.

- 9) Using the graph and formula below, determine the increased collector area that is necessary when the tilt angle is 30° for a solar space heating installation in an area where the latitude is 45° .

$$a = \frac{1}{e} - 1$$



Efficiency = $a = \frac{1}{0.84} - 1 = 0.19$ or 19%

- 10) The FCHART sizing method sizes collectors by use of curves generated by a computer in which specific system parameters are fed.

Answer the study questions below.

- a. A 300 square foot liquid collector array is installed in a house. What would be the largest and the smallest storage area necessary?

$$300 \text{ ft}^2 \times 1.5 \text{ ga/ft}^2 = 450 \text{ ga.}$$

$$300 \text{ ft}^2 \times 2.5 \text{ ga/ft}^2 = 750 \text{ ga.}$$

- b. In the house described above, the overnight heat load in January is 275,000 Btu. Assuming a temperature change of 50°F , what size of storage unit is necessary?

$$\begin{aligned} \text{Number of ga.} &= \frac{\text{Overnight Heat Load}}{8.34 \text{ lb/ga} \times 1 \text{ Btu/lb} \times \text{Storage Temperature Change}} \\ &= \frac{275,000}{8.34 \times 1 \times 50} = 659.5 \text{ ga} \end{aligned}$$

- c. In an ideal heat exchanger, how does the temperature of the storage loop liquid leaving the heat exchanger compare with the temperature of the collector loop liquid entering the heat exchanger?

The two temperatures would be equal

- d. What is meant by "approach temperature?" What approach temperature is achieved by most heat exchangers?

Approach temperature is the difference in temperature between entering fluid from the collector and leaving fluid from the heat exchanger. Most heat exchangers have a 10°F approach temperature.

- e. How is the operating temperature and efficiency of the collector array affected by decreasing approach temperature?

Operating temperature decreases. Collector efficiency increases with lower operating temperatures.

- f. What system information must be provided to heat exchanger manufacturers in order for them to be able to size heat exchangers for a given solar system?

Desired approach temperature 201
collector loop flow rate; Btu to be transferred
either minimum storage temperature or the flow rate from storage through the heat exchanger.

Answer the study questions below.

- a. Why is some type of expansion tank necessary in a liquid solar system?

The liquid expands when heated.

- b. Using the table below briefly describe how each type of expansion tank allows expansion. Mention advantages and disadvantages of each.

	<u>Operation</u>	<u>Advantages and Disadvantages</u>
Open Tank	Tank is open to atmosphere, so fluid can expand	Tank must be 3 feet or more above highest point in heating system. Open systems promote corrosion
Air cushion Tank	The tank is closed, but an air pocket is left, and compresses with fluid expansion.	Air dissolves in water & must be vented, sometimes emptying the air pocket in the tank, & leading to excessive system pressure.
Diaphragm air Cushion Tank	An impervious diaphragm between the air pocket liquid in the storage tank makes air absorption in the liquid impossible.	No air absorption into system occurs. Tank may be more expensive than other tanks.

- c. A system is filled with 65 gallons of water at 45° F and is then heated to 155° F. By what amount will the water expand?

$$65 \times 0.00025 \times 95 = 1.54 \text{ ga}$$

- d. In the system described in (c), by what amount will the liquid expand if it is 33% ethylene glycol? (maximum design temperature is 200° F)

$$1.37 \times 1.54 = 2.11 \text{ ga}$$

- e. For each of the factors listed below, indicate the conditions which must be met in order to select a heat duct coil:

air velocity across the coil- 500 to 600 ft/min

supply water temperature- 120 to 160° F

entering air temperature- 68-72° F

water temperature drop through the coil- 10-20° F

total system air flow rate- determined by auxiliary heating or cooling requirements

- f. If the auxiliary heat unit requires an air flow rate of 1000 cfm, and the face velocity is 400 fpm, what area of duct coil is required?

$$1000/400 = 2.5 \text{ ft}^2$$

- g. The space heating load in a liquid-to-air system is 68,000 Btuh. If there is a 15° F temperature drop through the heating coil, what volume of water must be pumped from storage?

$$\frac{68,000}{8.34 \times 60 \times 1 \times 15} = 9.06 \text{ gpm}$$

- h. A system has a 1600 cfm flow rate. In the heating coil the entering air temperature is 84° F. Entering water temperature is 150° F, with a flow rate of 7 gpm. What type of heat coil is necessary to satisfy a 78,100 Btuh heat load? (Refer to Table 6-5 in Fundamentals)

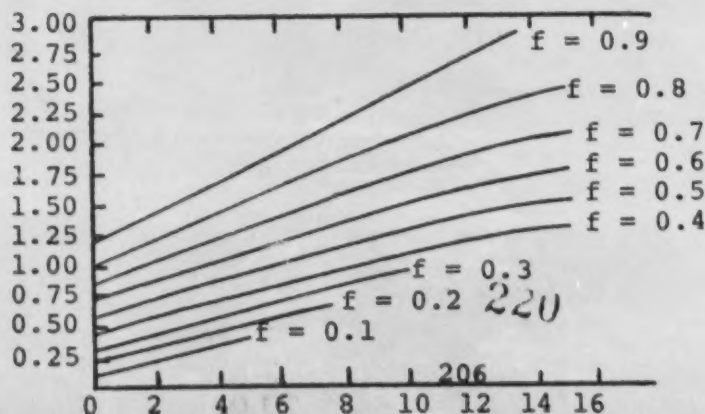
"Instructors Materials"

UNIT SB-8
PROGRESS CHECK (C-2)
PEER QUIZ

- a. The rule of thumb for liquid collector flow rate is 0.02 gpm/ft² of collector.
- b. The rule of thumb for estimating water storage size is 1.5 to 2.5 gallons/ft² of collector.
- c. With reference to heat exchangers, the approach temperature is the difference between the temperature of incoming collector fluid and outgoing fluid to the storage tank. This difference should be about 10 °F.
- d. Collector efficiency (increases, decreases) as approach temperature decreases.
- e. An open tank is different from an air cushion tank in that An open tank is open to the atmosphere, whereas an air cushion tank just contains an air pocket inside it, and is closed.
- f. Corrosion due to absorbed air is minimal in a diaphragm air cushion tank.
- g. To select a duct coil, air velocity across the coil should range from 500 to 600 feet per minute.
- h. To select a duct coil, storage temperature should be at least 120 °F.

- 1) Indicate whether each statement is true or false by circling T (true) or F (false).
- a. T (F) When determining the size of solar heating system components, the heat storage unit is sized first and all other components are sized in relation to it.
 - b. (T) F For space heating only, the optimum tilt angle for a collector is local latitude plus 15° .
 - c. T (F) The larger the approach temperature of the heat exchanger, the higher is collector efficiency.
 - d. T (F) In an air cushion tank, the heated liquid can expand without increasing system pressure because the tank is open to the atmosphere.
 - e. (T) F The F-Chart sizing technique requires information about characteristics specific to a given solar system.
 - f. T (F) The Los Alamos LC sizing method has separate divisors for air and liquid collector systems.
 - g. T (F) Most collector sizing methods make about the same assumptions, and take into account the same factors.
 - h. (T) F Collectors should be oriented to face south.
 - i. (T) F Liquid expansion due to heating is greater for a ethylene glycol solution than for pure water.
 - j. T (F) Research data suggests that a solar system that satisfies 80 to 90% of the heating requirements will be the most economical installation.
 - k. (T) F In the northern hemisphere, collector area is usually greater if solar energy is needed in the winter, rather than in the summer.
- 2) Complete each statement with the best answer.
- a. A rule of thumb for sizing collector area is that the collector area should be from $\frac{1}{3}$ to $\frac{1}{2}$ the floor area of the home.

- b. In an F-Chart, the X value is the ratio of monthly collector losses over monthly heating demand.
 - c. In the F-Chart collector sizing method, "f" represents The percent of total heating load supplied by the solar system.
 - d. A heat exchanger is used in the collector loop of a liquid system for the purpose of separating liquids in the collector & storage loops, thus allowing less expensive liquid to be used in the storage loop.
 - e. Most heat exchangers have an approach temperature of about 10 °F.
 - f. To size collector loop heat exchangers, the collector loop flow rate should be 0.02 gpm per square foot of installed collector.
 - g. To select an air heating coil, storage water temperature should range from 120 to 160 °F.
 - h. For a domestic hot water heating only, the collector tilt angle should be equal to local latitude
 - i. A rule of thumb for sizing liquid storage units is that they should hold 1.5 to 2.5 gallons per square foot of collector area.
 - j. The solar system sizing technique that has been programmed for computer use is the FCHART method.
 - k. The kind of expansion tank which allows the least amount of air absorption in the liquid is the diaphragm air cushion tank.
- 3) In the F-Chart below, if $x = 4$, and $y = 1.00$, what is the solar system's heating contribution?

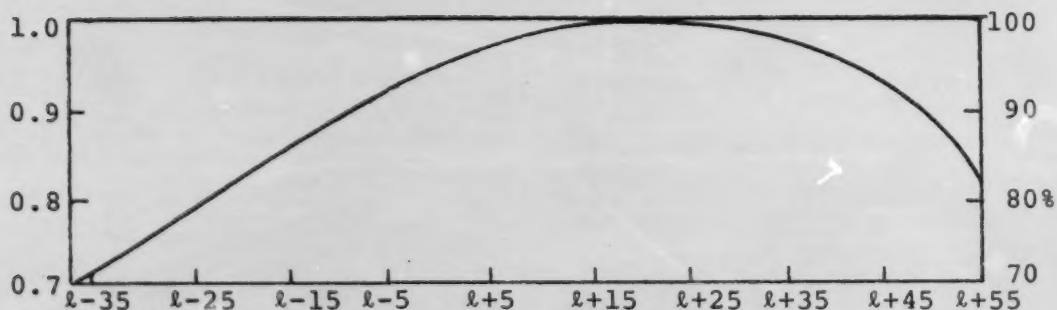


- 4) If the Btu input to a collector is 300 Btu/ft²/hr and the Btu output from the collector is 200 Btu/ft²/hr, what is the collector efficiency?

$$\frac{200}{300} = 0.67$$

- 5) Using the formula and graph below, determine the increase in collector area necessary when the collector in a solar heating system is tilted 15° in a location whose latitude is 40°.

$$a = \frac{1}{e} - 1$$



$$\frac{1}{0.78} - 1 = 0.30$$

Answer the study questions below:

- a. If gas costs \$0.31/therm, and a gas furnace is 60 percent efficient, what is the energy cost? A therm is 100,000 Btu, and has a volume of about 100 cubic feet.

$$\begin{array}{l} \$5.90 \text{ per mBtu} \\ \frac{\$5.90}{10} = \$0.59 \text{ per therm} \end{array}$$

- b. If the furnace described above is 50 percent efficient, what is the energy cost?

$$\begin{array}{l} \$7.00 \text{ per therm} \\ \frac{\$7.00}{10} = \$0.70 \text{ per therm} \end{array}$$

- c. If electricity for resistance heating costs \$0.04 per kWh, what is the energy cost?

$$\begin{array}{l} \$11.70 \text{ per mBtu} \\ \frac{\$11.70}{10} = \$1.17 \text{ per therm} \end{array}$$

- d. Assuming a 10 percent annual rate of inflation in natural gas costs, what will be the energy cost in 10 years for the conditions of Problem a (above)?

$$2.6 \times \$0.59/\text{therm} = \$1.53/\text{therm}$$

- e. Assuming an 8 percent annual rate of inflation in electricity costs, what will be the energy cost in 10 years for the conditions of Problem c (above)?

$$2.3 \times \$1.17/\text{therm} = \$2.69/\text{therm}$$

Answer the study questions below:

- a. Estimate the cost of a complete solar system which has 450 square feet of collector area.

$$450 \text{ ft}^2 \times \$25/\text{ft}^2 = \$11,250$$

- b. A solar system is estimated to cost \$10,200. The owner obtains a 20 year loan with interest at 10 percent and 20 percent required down payment. What is the annual mortgage payment on the loan?

$$0.80 \times 10,200 = \$8,160 \text{ must be borrowed}$$

$$0.1175 \times \$8,160 = \$958.8 \text{ is annual mortgage payment.}$$

- c. The solar system described above is located in an area where property is taxed at 40 percent of its actual value. The tax rate is 41 mills (\$41 on every \$1,000, or 0.041). What is the annual property tax on the solar system?

$$\text{Property tax} = \$10,200 \times 0.40 \times 0.041 = \$167.28$$

- d. The annual mortgage payment on a solar system is \$1,200 per year with a 10 percent interest rate. When 15 years remain on the mortgage, what amount of that years mortgage payment is interest?

$$0.77 \times \$1,200 = \$924.$$

- e. The individual who owns the system described above is in a 30 percent tax bracket for federal income tax purposes. What amount of income tax credit will s/he receive for paying the interest on the loan?

$$\text{Income tax credit} = \$924 \times 0.30 = 277.2$$

- f. How does the energy operating cost of a solar system compare to that of a non-solar system?

A solar system has higher operating costs.

"Instructors Materials"

UNIT SB-9
PROGRESS CHECK (C-1)
WRITTEN QUIZ

- a. If gas costs \$0.40/therm and a gas furnace is 60 percent efficient, what is the energy cost?

\$5.70/m Btu or \$0.57/therm

- b. Assuming an 8 percent annual rate of inflation in natural gas costs, what will be the energy cost in 20 years for the case described in question a?

$$4.7 \times \$0.57/\text{therm} = \$2.68/\text{therm}$$

- c. What is the current cost of natural gas in your area?

- d. Estimate the cost of a complete solar system with a collector area of 500 ft².

$$500 \text{ ft}^2 \times \$25/\text{ft}^2 = \$12,500$$

- e. List below the financial costs and benefits which should be included in calculating the annual cost of a solar system.

mortgage payments
property taxes
insurance
credit on income taxes
operating costs
maintenance costs

- f. A family borrows \$9,000 from a bank for 18 years at a 9 percent interest rate. What is their annual mortgage payment? Use the figure provided on the next page.

$$0.115 \times 9000 = \$1,035$$

LIFE-CYCLE COST ANALYSIS LCA-1 WORKSHEET — BASIC DATA

BUILDING DATA

Line 1. Building Annual Heat Load
(from Col. C Total of Step 2A Worksheet in EQUIPMENT SELECTION Section) 100 mBtu

Line 2. Hot Water Load
(from Col. D Total of Step 2A Worksheet in EQUIPMENT SELECTION Section) 15 mBtu

Line 3. Total Annual Heating Load
(Line 1 100) + (Line 2 15) = ... 115 mBtu

SOLAR SYSTEM DATA

Line 4. Collector Area
(from Line 7 of Step 2B Worksheet in EQUIPMENT SELECTION Section) 400 sq. ft.

Line 5. Fraction of Annual Heating Load Carried by Solar
(from Line 14 of Step 2B Worksheet in EQUIPMENT SELECTION Section) 50 %

Line 6. Unit Cost of Solar System Installed 20 \$/sq. ft.

Line 7. Installed Cost of Solar System:
(Line 4 400) x (Line 6 20) = ... 8000 \$

Line 8. Type of Auxiliary Fuels:
8a. Space electric 8b. Hot Water electric

Line 9. Efficiencies of Auxiliary Fuels:
9a. Space 100 % 8b. Hot Water 100 %

Line 10. Auxiliary Fuel Costs (from Figs. 1 & 2):
10a. Space 8.80 \$/mBtu 10b. Hot Water 8.80 \$/mBtu

FINANCIAL DATA

Line 11. Terms of Loan: Years 20 Interest Rate 9 %

Line 12. Down Payment on Loan: (20 %) x (Line 7 8000) = ... 1600 \$

Line 13. Amount of Loan: (Line 7 8000) - (Line 12 1600) = ... 6400 \$

Line 14. Annual Mortgage Payment:
(Factor from Fig. 4 .11) x (Line 13 6400) = ... 704 \$/year

TAXES AND INSURANCE

Line 15. Property Tax:
15a. Ratio of Taxable Value to Installed Cost 50 %
15b. Property Tax Rate 2 %
15c. Property Tax:
(Line 7 8000) x (Line 15a. .50) x (Line 15b. .02) = ... 80 \$/year

Line 16. Income Tax Rate:
16a. Federal Tax Rate 30 %
16b. State Tax Rate 10 %
16c. Effective Income Tax Rate:
(Line 16a. 30) + (Line 16b. 10) - [2 x (Line 16a. 30)
x (Line 16b. 10)] = ... 36 %

Line 17. Insurance:
(Line 7 8000) x (Insurance Rate .005) = ... 40 \$/year

OPERATION AND MAINTENANCE

Line 18. First Year Operating Cost:
18a. Annual Solar Heat Supplied:
(Line 5 .50) x (Line 3 115) = ... 57.5 mBtu
18b. Fraction of Solar for Electricity 5 %
18c. Operating Cost:
(Line 18a. 57.5) x (Line 18b. 5) x (Line 10a. 8.80) = ... 25 \$/year

Line 19. First Year Maintenance Cost = ... 100 \$/year

NON-SOLAR SYSTEM DATA

Line 20. First Year Fuel Expenses:
20a. Space: (Line 1 100) x (Line 10a. 8.80) = ... 880 \$/year
20b. Hot Water: (Line 2 15) x (Line 10b. 8.80) = ... 132 \$/year
20c. Total Fuel Expenses:
(Line 20a. 880) + (Line 20b. 132) = ... 1012 \$/year

Line 21. First Year Operating Expenses:
(Line 20c. 1012) x (3 %) = ... 30 \$/year

Line 22. First Year Fuel and Operating Expenses:
(Line 20c. 1012) + (Line 21. 30) = ... 1042 \$/year

LCA-2 WORKSHEET — SOLAR CASH FLOWS

KEY:

Annual Mortgage Rate 9 %
(from Line 11)

Auxiliary Inflation Rate 7 %

General Inflation Rate 6 %

Collector Area 400 sq. ft.
(from Line 4)

Solar Fraction of Total Load 50 %
(from Line 5)

System Cost 8000 \$
(from Line 7)

Down Payment 1600 \$
(from Line 12)

Col. A	Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I	Column J	Column K	Column L
YEAR	ANNUAL MORTGAGE PAYMENT (from Line 14)	YEARS LEFT ON MORTGAGE	FRACTION OF MORTGAGE AS INTEREST (from Fig. 4)	INTEREST PAID (Col. B x Col. D)	AUXILIARY FUEL COST (See Note 1)	PROPERTY TAX (See Note 2)	INSURANCE (See Note 3)	OPERATING COST (See Note 4)	MAINTENANCE COST (See Note 5)	INCOME TAX SAVINGS (Col. E x Line 16c)	EXPENSE WITH SOLAR (See Note 6)
1	704	20	.820	577	440	80	40	22	100	208	2778
2		19	.805	567	471			24	106	204	1221
3		18	.785	553	504			25	112	199	1266
4		17	.765	539	539			27	119	194	1315
5		16	.745	525	577			29	126	189	1367
6		15	.720	507	617			31	134	183	1423
7		14	.700	493	660			33	142	177	1482
8		13	.670	472	707			35	150	170	1546
9		12	.640	451	756			38	159	162	1615
10		11	.610	429	809			40	169	154	1688
11		10	.575	405	866			43	179	146	1766
12		9	.540	380	926			46	190	137	1849
13		8	.500	352	991			50	201	127	1939
14		7	.450	317	1060			53	213	114	2036
15		6	.400	282	1135			57	226	102	2140
16		5	.350	246	1214			61	240	89	2250
17		4	.290	204	1298			65	254	73	2368
18		3	.230	162	1390			69	269	58	2494
19		2	.160	113	1487			74	285	41	2629
20		1	.085	60	1593			80	303	22	2778

Note 1. First year cost:
(Line 3 _____) x (1.0 — Line 5 _____) x (Line 10a. _____)
Second and future years: (Previous Year Cost) x (1 + Fuel Inflation Rate)

Note 2. First Year Cost: (Line 15c.)
Second and Future Years: (Previous Year Cost) x (1 + General Inflation Rate)

Note 3. First Year Cost: (Line 17)
Second and future years: (Previous Year Cost) x (1 + General Inflation Rate)

Note 4. First Year Cost: (Line 18)
Second and Future Years: (Previous Year Cost) x (1 + Fuel Inflation Rate)

Note 5. First Year Cost: (Line 19)
Second and Future Years: (Previous Year Cost) x (1 + General Inflation Rate)

Note 6. First Year Cost:
(Down Payment) + (Col. B) + (Col. F) + (Col. G) + (Col. H) + (Col. I) + (Col. J) — (Col. K)
Second and Future Years: (Cols. B+F+G+H+I+J—K)

LIFE-CYCLE COST ANALYSIS

LCA-3 WORKSHEET — ECONOMIC SUMMARY

KEY:

Fuel Inflation Rate 7 %

Col. M	Column N	Column O	Column P	Column Q	Column R	Column S	Column T	Column U	Column V	Column W
YEAR	NON-SOLAR SYSTEM	SOLAR SYSTEM								
	FUEL PLUS OPERATING EXPENSE (See Note 1.)	COLLECTOR AREA _____ sq ft			COLLECTOR AREA _____ sq ft			COLLECTOR AREA _____ sq ft		
		EXPENSE WITH SOLAR (From Col. L)	SAVINGS WITH SOLAR (Col. N) — (Col. O)	CUMULATIVE SAVINGS WITH SOLAR (See Note 2)	EXPENSE WITH SOLAR (From Col. L)	SAVINGS WITH SOLAR (Col. N) — (Col. O)	CUMULATIVE SAVINGS WITH SOLAR (See Note 2)	EXPENSE WITH SOLAR (From Col. L)	SAVINGS WITH SOLAR (Col. N) — (Col. O)	CUMULATIVE SAVINGS WITH SOLAR (See Note 2)
1	1042	2778	-1736	-1736						
2	1115	1221	-106	-1842						
3	1193	1266	-73	-1915						
4	1278	1315	-39	-1954						
5	1366	1367	-1	-1955						
6	1461	1423	38	-1917						
7	1564	1482	82	-1835						
8	1673	1546	127	-1708						
9	1790	1615	175	-1533						
10	1916	1688	228	-1305						
11	2050	1766	284	-1021						
12	2193	1849	344	-677						
13	2347	1939	408	-269						
14	2511	2036	475	+206						
15	2687	2140	547	+753						
16	2875	2250	625	+1378						
17	3076	2368	708	+2085						
18	3291	2494	797	+2883						
19	3522	2629	893	+3776						
20	3768	2778	990	+4766						

Note 1. First Year Cost: (Line 22)
 Second and Future Years:
 (Previous Year Cost) x (1 + Fuel Inflation Rate)

Note 2. First Year Savings: (Col. P First Year)
 Second and Future Years:
 (Previous Year) + (Col. P)

- a. For the solar system in Podunk, U.S.A. (analysed in Assignment Sheet SB-9-7) identify:

number of years until positive savings 5

number of years until payback 17

- b. For the solar system described in the Lennox manual (Economics, p. 8-10), identify:

number of years until positive savings 5

number of years until payback 18

LIFE-CYCLE COST ANALYSIS
LCA-1 WORKSHEET — BASIC DATA

BUILDING DATA

Line 1. Building Annual Heat Load
(from Col. C Total of Step 2A Worksheet in EQUIPMENT SELECTION Section) 87 mBtu

Line 2. Hot Water Load
(from Col. D Total of Step 2A Worksheet in EQUIPMENT SELECTION Section) 15 mBtu

Line 3. Total Annual Heating Load
(Line 1 87) + (Line 2 15) = ... 102 mBtu

SOLAR SYSTEM DATA

Line 4. Collector Area
(from Line 7 of Step 2B Worksheet in EQUIPMENT SELECTION Section) 350 sq. ft.

Line 5. Fraction of Annual Heating Load Carried by Solar
(from Line 14 of Step 2B Worksheet in EQUIPMENT SELECTION Section) 60 %

Line 6. Unit Cost of Solar System Installed 25 \$/sq. ft.

Line 7. Installed Cost of Solar System:
(Line 4 350) x (Line 7 25) = ... 8750 \$

Line 8. Type of Auxiliary Fuels:
8a. Space electric 8b. Hot Water electric

Line 9. Efficiencies of Auxiliary Fuels:
9a. Space 100 % 8b. Hot Water 100 %

Line 10. Auxiliary Fuel Costs (from Figs. 1 & 2):
10a. Space 11.7 \$/mBtu 10b. Hot Water 11.7 \$/mBtu

FINANCIAL DATA

Line 11. Terms of Loan: Years 20 Interest Rate 9 %

Line 12. Down Payment on Loan: (20 %) x (Line 7 8750) = ... 1750 \$

Line 13. Amount of Loan: (Line 7 8750) - (Line 12 1750) = ... 7000 \$

Line 14. Annual Mortgage Payment:
(Factor from Fig. 4 .11) x (Line 13 7000) = ... 770 \$/year

TAXES AND INSURANCE

Line 15. Property Tax:
15a. Ratio of Taxable Value to Installed Cost 40 %
15b. Property Tax Rate .04 %
15c. Property Tax:
(Line 7 8750) x (Line 15a. .40) x (Line 15b. .04) = ... 140 \$/year

Line 16. Income Tax Rate:
16a. Federal Tax Rate 25 %
16b. State Tax Rate 8 %
16c. Effective Income Tax Rate:
(Line 16a. 25) + (Line 16b. 8) - [2 x (Line 16a. 25)]
x (Line 16b. 8) = ... 29 %

Line 17. Insurance:
(Line 7 8750) x (Insurance Rate .005) = ... 43.75 \$/year

OPERATION AND MAINTENANCE

Line 18. First Year Operating Cost:
18a. Annual Solar Heat Supplied:
(Line 5 .60) x (Line 3 102) = ... 61.2 mBtu
18b. Fraction of Solar for Electricity .04 %
18c. Operating Cost:
(Line 18a. 61.2) x (Line 18b. .04) x (Line 10a. 11.7) = ... 28.64 \$/year

Line 19. First Year Maintenance Cost = ... 90. \$/year

NON-SOLAR SYSTEM DATA

Line 20. First Year Fuel Expenses:
20a. Space: (Line 1 87) x (Line 10a. 11.7) = ... 1017.9 \$/year
20b. Hot Water: (Line 2 15) x (Line 10b. 11.7) = ... 175.5 \$/year
20c. Total Fuel Expenses:
(Line 20a. 1017.9) + (Line 20b. 175.5) = ... 1193.4 \$/year

Line 21. First Year Operating Expenses:
(Line 20c. 1193.4) x (3 %) = ... 35.80 \$/year

Line 22. First Year Fuel and Operating Expenses:
(Line 20c. 1193.4) + (Line 21. 35.80) = ... 1229.20 \$/year

LIFE-CYCLE COST ANALYSIS
LCA-2 WORKSHEET — SOLAR CASH FLOWS

KEY:

Annual Mortgage Rate 9 %
(from Line 11)

Solar Fraction of Total Load 60 %
(from Line 5)

Auxiliary Inflation Rate 7 %

System Cost 8750 \$
(from Line 7)

General Inflation Rate 8 %

Down Payment 1750 \$
(from Line 12)

Collector Area 350 sq. ft.
(from Line 4)

Col. A	Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I	Column J	Column K	Column L
YEAR	ANNUAL MORTGAGE PAYMENT (from Line 14)	YEARS LEFT ON MORTGAGE	FRACTION OF MORTGAGE AS INTEREST (from Fig. 4)	INTEREST PAID (Col. B x Col. D)	AUXILIARY FUEL COST (See Note 1.)	PROPERTY TAX (See Note 2.)	INSURANCE (See Note 3.)	OPERATING COST (See Note 4.)	MAINTENANCE COST (See Note 5.)	INCOME TAX SAVINGS (Col. E x Line 16c.)	EXPENSE WITH SOLAR (See Note 8.)
1	770	20	.825	635.25	477.36	140.00	43.75	28.64	90.00	184.22	3115.33
2		19	.810	623.70	510.78			30.64	97.20	180.87	1411.50
3		18	.790	608.30	546.53			32.79	104.98	176.41	1461.64
4		17	.770	592.90	584.79			35.09	113.37	171.94	1515.06
5		16	.740	569.80	652.72			37.54	122.44	165.24	1601.21
6		15	.725	558.25	669.52			40.17	132.24	161.89	1633.79
7		14	.700	539.00	716.39			42.98	148.82	156.31	1699.63
8		13	.670	515.90	766.54			45.99	154.24	149.61	1770.91
9	✓	12	.650	500.50	820.19	✓	✓	49.21	166.58	145.15	1844.58
10		11	.610	469.70	877.61			52.66	179.91	136.21	1927.72
11		10									
12		9									
13		8									
14		7									
15		6									
16		5									
17		4									
18		3									
19		2									
20		1									

Note 1. First year cost:
(Line 3 _____) x (1.0 — Line 5 _____) x (Line 10a. _____)
Second and future years: (Previous Year Cost) x (1 + Fuel Inflation Rate)

Note 2. First Year Cost: (Line 15c.)
Second and Future Years: (Previous Year Cost) x (1 + General Inflation Rate)

Note 3. First Year Cost: (Line 17)
Second and future years: (Previous Year Cost) x (1 + General Inflation Rate)

Note 4. First Year Cost: (Line 18)
Second and Future Years: (Previous Year Cost) x (1 + Fuel Inflation Rate)

Note 5. First Year Cost: (Line 19)
Second and Future Years: (Previous Year Cost) x (1 + General Inflation Rate)

Note 6. First Year Cost:
(Down Payment) + (Col. B) + (Col. F) + (Col. G) + (Col. H) + (Col. I) + (Col. J) — (Col. K)
Second and Future Years: (Cols. B+F+G+H+I+J—K)

LIFE-CYCLE COST ANALYSIS
LCA-3 WORKSHEET — ECONOMIC SUMMARY

KEY:

Fuel Inflation Rate 7 %

Col. M	Column N	Column O	Column P	Column Q	Column O	Column P	Column Q	Column O	Column P	Column Q
YEAR	NON-SOLAR SYSTEM	SOLAR SYSTEM								
	FUEL PLUS OPERATING EXPENSE (See Note 1.)	COLLECTOR AREA _____ sq ft			COLLECTOR AREA _____ sq ft			COLLECTOR AREA _____ sq ft		
		EXPENSE WITH SOLAR (From Col. L)	SAVINGS WITH SOLAR (Col. N) — (Col. O)	CUMULATIVE SAVINGS WITH SOLAR (See Note 2.)	EXPENSE WITH SOLAR (From Col. L)	SAVINGS WITH SOLAR (Col. N) — (Col. O)	CUMULATIVE SAVINGS WITH SOLAR (See Note 2.)	EXPENSE WITH SOLAR (From Col. L)	SAVINGS WITH SOLAR (Col. N) — (Col. O)	CUMULATIVE SAVINGS WITH SOLAR (See Note 2.)
1	1229.20	3115.33	-1886.13	-1886.13						
2	1327.54	1411.50	-83.96	-1970.09						
3	1433.74	1461.64	-27.90	-1997.99						
4	1548.44	1515.06	33.38	-1964.61	← Time of positive savings is 4th year.					
5	1672.31	1601.21	71.10	-1893.51						
6	1806.10	1633.79	172.31	-1721.20						
7	1950.59	1699.63	250.96	-1470.24						
8	2106.63	1770.91	335.72	-1134.52						
9	2275.16	1844.58	430.58	-703.94						
10	2457.18	1929.72	529.46	-174.48						
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										

Note 1. First Year Cost: (Line 22)
Second and Future Years:
(Previous Year Cost) x (1 + Fuel Inflation Rate)

Note 2. First Year Savings: (Col. P First Year)
Second and Future Years:
(Previous Year) + (Col. P)

- a. A solar domestic hot water (DHW) system saves money (more, less) quickly than does a space heating system because it makes use of solar energy year-round, and requires only moderate collector temperature.
- b. Three basic types of solar DHW systems are:
 - 1) direct heating/thermosiphon
 - 2) indirect heating/pump circulating
 - 3) direct heating/pump circulating
- c. List the major components of a typical solar DHW system (see Figure 8-2 in Fundamentals).
collectors, hot water tank, compression tank, heat exchanger, temperature sensor, differential thermostat.
- d. In the space below, draw a simple thermosiphon system. Label its parts and the directions of fluid flow.
- e. A thermosiphon system is an (active, passive) system.
- f. Two differences between a thermosiphon DHW system and other DHW systems are that a thermosiphon system is an (active, passive) system and a thermosiphon system requires the storage tank to be located 1-2 feet above the collectors.

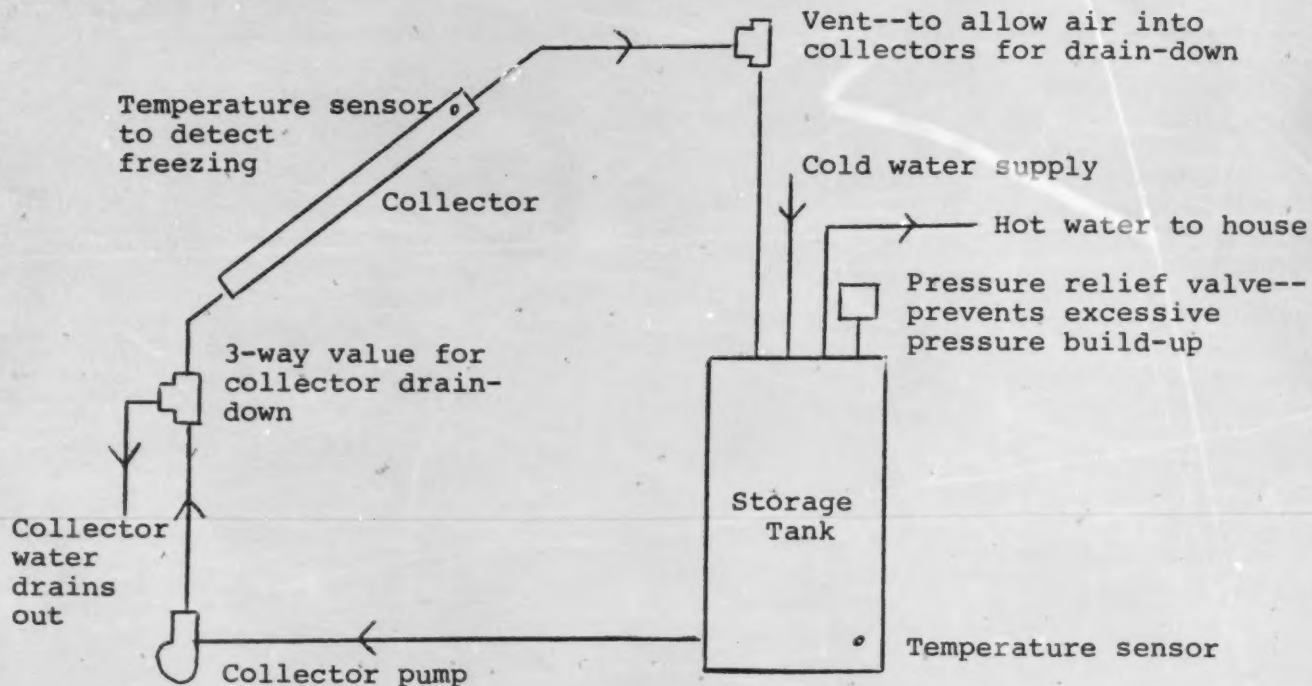
- g. In the table below, list problems with thermosiphon systems, and corrective measures, where available.

<u>Problem</u>	<u>Corrective Measure</u>
1. Variations in insolation lead to variations in water temperature.	1. include an auxiliary water heater to moderate water temperature
2. The requirement that the water tank be above the collectors makes system design difficult.	2.
3. Liquid freezing in the collectors may be a problem in cold climates.	3. Allow drain down from collectors, installing a valve between collector and storage to prevent tank draining.
4. Water temperature may rise above safe levels.	4. Include safety valves to reduce excess pressure.

- h. List below some advantages to thermosiphon DHW systems.

1. relatively inexpensive to install.
2. relatively easy to install.
3. relatively inexpensive to operate.

- a. In the space below, diagram a drain-down system for a direct heating/pump circulating DHW system. Label each part, and its function. Label the direction of fluid flow.



- b. The controls for drain-down should be mechanical and should not rely on electricity because electricity may be unavailable in severe weather.
- c. In a drain-down circulating system when storage temperature is below 180 °F, and collector temperature is above 32 °F, and exceeds storage temperature by 10 °F, the collector pump should go on.
- d. A drain-down system should drain down when the collector temperature sensor indicates the temperature is below 32 °F.
- e. In a one tank solar DHW system, an auxiliary electric heating element may be installed near the top of the tank.
- f. What are the advantages of a two tank solar DHW system?
 Auxiliary heat energy is used less in a two tank system. Solar energy only is used to heat one tank, and the backup system is turned on only when solar energy is insufficient to achieve a specific water temperature.

- a. What two components are usually added to an indirect heating/circulating system, but not included in the DHW system previously discussed? What is the function of each?
 1. heat exchanger - to transfer heat between collector and storage loops.
 2. pump - to circulate liquid through storage loop.
- b. The extra pump may be unnecessary if:
 - 1) the heat exchanger is located below the storage tank
 - 2) thermosiphon action is able to circulate water from storage tank to heat exchanger
 - 3) a heat exchanger which wraps around the storage tank is used
- c. List below two possible problems with liquid solar DHW systems, and a corrective measure for each.

Problem

Corrective Measure

- | | |
|--|--|
| 1) entry of excessively hot water into hot water service line. | 1) install a mixing or tempering valve between solar storage tank and conventional water heater to moderate water temperature. |
| 2) high temperature pressure may damage system | 2) install pressure relief valves |

- d. In the collector loop, the pressure relief valve is usually set to discharge at pressures in excess of 50 psi, and must be plumbed to an open drain because the vented fluid is very hot and non-potable.
- e. To allow for the pressure build-up and fluid expansion that occur with heating, a storage tank may be equipped with an expansion tank and a pressure relief valve.
- f. The heat-exchanger used in solar DHW systems must usually be double-walled to minimize water contamination.
- g. List the types of heat exchangers that are most suitable for DHW systems.
 - shell and double tube
 - double wall (tubing wrapped around and bonded to tank)
 - parallel tube heat exchanger (double-walled)

- h. List below the advantages and disadvantages of using air collectors in solar DHW systems.

Advantage

1. no possibility of damage due to collector loop liquid leakage.
2. no boiling or freezing problems in collector loop.
3. no need for expensive fluid in collector loop.

Disadvantage

1. piping between collector and heat exchanger must be larger.
2. more energy is required for the fluid circulator (fan)
3. larger collectors needed.

- i. An air collector DHW system must always use the type of system that has been referred to as an indirect circulating system.
- j. In direct and indirect DHW systems, a differential temperature controller measures the temperature difference between collector and storage. A difference of 10 °F turns the pump on. When that difference is reduced to 3 °F, the pump goes off.

ANALYZING DHW SYSTEMS

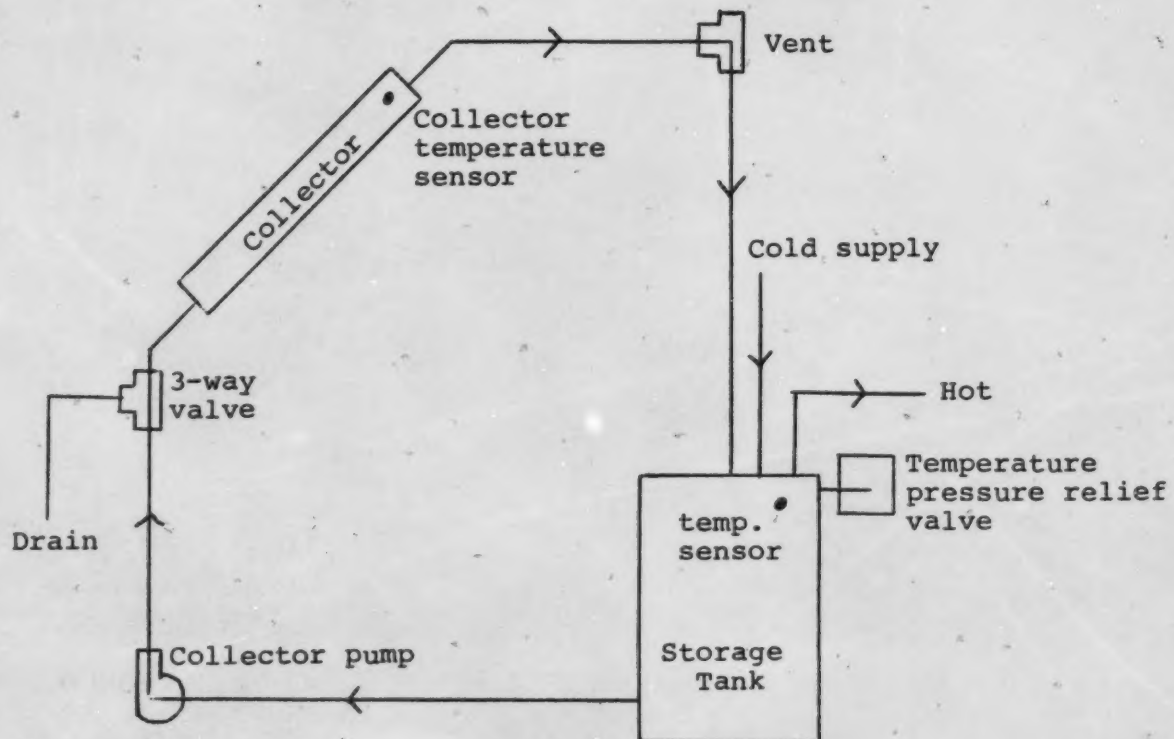
Review the DHW system diagrams in Fundamentals. Describe the systems presented in the figures listed below by completing the table.

Figure Number	Direct or Indirect?	Circulating or Thermosiphon?	Heat Exchanger in Collector Loop?	Kind of Freeze Protection	Number of Storage Tanks?
8-1	Indirect	Circulating	Yes	Antifreeze Liquid	1
8-2	Direct	Thermosiphon	No	Drain down	1
8-4	Direct	Circulating	No	Drain-down	1
8-5	Direct	Circulating	No	Electric heating	1
8-6	Direct	Circulating	No	Drain down	2
8-7	Indirect	Circulating	Yes	Antifreeze Liquid	2
8-13	Indirect	Circulating	Yes	Air Collector	2

Also, try to identify components used in each system to avoid overpressurization or overheating.

- 1) Indicate whether each statement is true or false by circling T (true) or F (false).
 - a. T (F) In a thermosiphon system, heated water settles and flows down into the storage tank.
 - b. T (F) A thermosiphon system can never be used in freezing climates.
 - c. (T) F A collector storage temperature difference of about 10° F usually starts the pump in circulating systems.
 - d. (T) F A freeze protection system should be designed to avoid reliance on electrical power.
 - e. T (F) The heating coil for auxiliary water heating should be located at the bottom of the storage tank.
 - f. (T) F A two-tank DHW system makes more efficient use of electric energy than a one-tank system.
 - g. T (F) Air collectors can be used only in direct DHW systems.
 - h. (T) F A fan in an air heating DHW system requires more energy than the pumps used in liquid systems.
 - i. T (F) A DHW system can use solar energy only in the winter.
- 2) Complete each statement as precisely as you can.
 - a. In a thermosiphon system, the storage tank must be located 1-2 feet above the collector.
 - b. A thermosiphon system is a (direct, indirect) water heating system.
 - c. In direct heating, pump circulating systems, excessive pressure in the system may be relieved by installing a pressure relief valve in the collector loop.
 - d. Drain-down is used for the purpose of avoiding liquid freezing on the collector.
 - e. Indirect DHW systems are distinguished from direct hot water systems in that they include antifreeze solution in the liquid in the collector loop, and must always include a heat exchanger as a component in the collector loop.

- f. To prevent excessively hot water from entering the DHW service line, a mixing or tempering valve is installed between the solar and conventional hot water tanks.
 - g. Two devices used to avoid excessive pressure in the storage tank are the pressure relief valve and the expansion tank.
 - h. In DHW systems, the heat exchanger must always be constructed so as to be double walled.
 - i. A 40 to 60 gallon water tank is usually adequate for solar DHW systems.
- 3) The diagram below illustrates an incomplete direct heating/ circulating DHW system with drain-down capability. Label each component shown, and the direction of hot and cold water flow. Draw in and label the components and piping necessary for completing the system.



NARRATION SCRIPT
SOLAR DOMESTIC HOT WATER SYSTEMS:
SOME EXAMPLES

Solar Systems
UNIT SB-10

SLIDE #1 (VMC TITLE SLIDE)

(Music up then down under narration).

SLIDE #2 (SLIDE SET TITLE SLIDE)

One of the most economical ways to take advantage of solar energy is by using it to heat hot water for home use. Let's examine some installed systems, and their components.

SLIDE #3 (PHOTO OF TWO COLLECTORS ON ROOF)

A solar domestic hot water system is less expensive and easier to install than a space heating system because only a few collectors are necessary to satisfy the water heating load. Here we see two collectors used for water heating, mounted on a rack on the south side of a roof. The collectors are on the back of the roof, where they cannot be seen from the street.

SLIDE #4 (CLOSE UP ON TWO COLLECTORS ON ROOF)

Examining the collectors more closely, note the insulated supply manifold on the bottom of the collectors, and the insulated return manifold directing the heated water to the storage tank in the basement.

SLIDE #5 (DRAWING OF TWO COLLECTORS ON ROOF)

On the return manifold are installed an air vent, used to eliminate air from this closed system, and a fill valve, used to fill the system. Both are insulated against freezing.

SLIDE #6 (BASEMENT DHW INSTALLATION)

The remainder of the system is in the basement. This is a one tank system with auxiliary electric heat being provided to the tank containing the solar-heated water. Note that most of the copper piping is insulated, except for the lines which release pressure to the outside, and which connect with the service hot water system.

SLIDE #7 (SCHEMATIC OF BASEMENT INSTALLATION)

Note the red collector loop pump, which identifies this system as an active, circulating hot water system. The green expansion tank prevents system over-pressurization. A small control box monitors collector and storage temperatures, and controls pump operation.

SLIDE #8 (PHOTO OF TWO COLLECTORS MOUNTED ON GROUND)

Collectors for domestic hot water systems are often mounted on racks on the ground as seen here.

SLIDE #9 (CLOSE-UP OF TWO COLLECTORS)

Note the supply manifold on the bottom and the return manifold at the top of the collector array. A filling valve is installed on the upper manifold.

SLIDE #10 (PHOTO OF BASEMENT INSTALLATION)

In this case the storage tank is covered with insulation and an aluminum outside cover to prevent heat loss from the storage tank. The piping to and from the collectors is also insulated. Note the pump and expansion tank in the loop returning to the collectors, and the small control box above them. The insulated piping from the top of the tank supplies hot water to the house.

SLIDE #11 (PHOTO OF LARGE COLLECTOR ARRAY ON ROOF)

Domestic hot water systems are frequently integrated with space heating systems. This collector array provides energy for space and water heating.

SLIDE #12 (PHOTO OF SPACE-DHW BASEMENT INSTALLATION)

In the basement installation, the main liquid storage tank is behind the concrete wall on which the pumps are mounted. The conventional electric water heater draws heat from the solar-heated liquid in the main tank.

DIRECT GAIN

Perform the following calculations:

- (1) If a house has 200 square feet of south-facing window, how much heat capacity would be recommended?

a) for direct sunlight?

$$200 \text{ ft}^2 \times 30 \text{ Btu/ft}^2/^{\circ}\text{F} = 6000 \text{ Btu}/^{\circ}\text{F}$$

b) for indirect heat storage?

$$200 \text{ ft}^2 \times 120 \text{ Btu/ft}^2/^{\circ}\text{F} = 24,000 \text{ Btu}/^{\circ}\text{F}$$

- (2) Using the heat capacity table in Unit SB-2, make one recommendation about how to get the necessary capacity.

$$\begin{aligned} 6000 \text{ Btu}/^{\circ}\text{F} \text{ requires } & (6000 \text{ Btu}/^{\circ}\text{F} \div (31.7 \text{ Btu/ft}^3/^{\circ}\text{F})) \\ & = 189 \text{ Ft}^3 \text{ of concrete, or} \\ & 189 \div .33 = 573 \text{ ft}^2 \text{ of 4" thick} \\ & \text{concrete slab, or a} \\ & \text{15' x 38' x 4" thick} \\ & \text{slab, for one example.} \end{aligned}$$

- (3) Repeat exercise (2), making a different recommendation.

$$\begin{aligned} 6000 \text{ Btu}/^{\circ}\text{F} \text{ requires } & (6000 \text{ Btu}/^{\circ}\text{F} \div (24.6 \text{ Btu/ft}^3/^{\circ}\text{F})) \\ & = 244 \text{ ft}^3 \text{ brick, or} \\ (244 \text{ ft}^3 \div \frac{1}{4} \text{ ft thick}) & = 976 \text{ ft}^2 \text{ of brick floor or wall} \\ & \text{required, or a 122' x 8' x } \frac{1}{4} \text{ ft} \\ & \text{thick wall} \end{aligned}$$

- (4) Assume a 200-day heating season. Using the table "Solar Heat Gain through Use of South Glass" from Information Sheet SC-1-1, compute the total seasonal net gain in Atlanta for each square foot of south facing, double-glazed window.

$$200 \text{ days} \times 24 \text{ hrs/day} \times 18.8 \text{ Btu/hr/ft}^2 = 90,240 \text{ Btu/ft}^2 \text{ of south glazing}$$

Part I. (50 points)

Write a brief report on your contributions to the two demonstration projects in Job Sheets SC-1-2, SC-1-3. Come to an agreement with your instructor regarding the grade your efforts deserve. This grade will count for half your grade on this unit.

Part II. (50 points)

1. Suppose a certain house has 200 ft^2 of south-facing window. If the contribution of double glazing is $18.8 \text{ Btu/ft}^2/\text{hr}$, what is the total heating contribution of this glazing during a 200-day heating season? (4 points)

$$200 \times 18.8 \times 24 = 90,240 \text{ Btu per season}$$

2. Approximately how much heat capacity should be available for good use of this net gain? Suppose half is to be met with surfaces exposed to sunlight, and half from surfaces indirectly heated. (4 points)

$$\begin{aligned} 100 \text{ ft}^2 \text{ of direct exposure} &\rightarrow 100 \times 30 \text{ Btu/}^\circ\text{F} = 3000 \text{ Btu/}^\circ\text{F} \\ 100 \text{ ft}^2 \text{ of material not exposed to sun} &\rightarrow (100 \times 120 \text{ Btu/}^\circ\text{F}) \\ &= 12,000 \text{ Btu/}^\circ\text{F}, \end{aligned}$$

$$\text{Total} = 15,000 \text{ Btu/}^\circ\text{F} \text{ heat capacity needed}$$

3. Take a total heat capacity, needed for use of the direct solar gain, of $15,000 \text{ Btu/}^\circ\text{F}$. If stone concrete has a heat capacity of $31.7 \text{ Btu/ft}^3/\text{}^\circ\text{F}$, what area of 6" slab would provide this? (5 points)

$$(15,000 \text{ Btu/}^\circ\text{F}) \div (31.7 \text{ Btu/ft}^3/\text{}^\circ\text{F}) = 473 \text{ ft}^3 \text{ stone concrete needed.}$$

$$\begin{aligned} \text{If the concrete slab is } \frac{1}{2} \text{ ft thick, then Total Area Needed} &= \\ 473 \div \frac{1}{2} &= 946 \text{ ft}^2 \text{ stone concrete needed.} \end{aligned}$$

4. What is the minimum recommended distance between upper and lower vents in a Trombe wall?
(4 points)

6 Feet

What is the function of the backdraft damper in lower vents of Trombe walls and thermosiphoning air heaters?
(4 points)

It permits cool air from entering the room from the exterior surface of the wall.

6. Wood separators are recommended between glazing surface and the Trombe wall or the collector surface of the air heater. Why are these necessary?
(4 points)

To prevent heat loss to the outside from the warmed surfaces.

7. Why is a thermosiphoning air heater most efficient when used in schools or low-rise office buildings?
(5 points)

These structures have high heat loads in the daytime, enabling greatest use of the heater's output.

8. Why is glass recommended for the glazing on the thermosiphoning air heater, rather than plastic?
(3 points)

Collection temperatures are higher on the air heater.

9. Which produces more $\text{Btu/ft}^2/\text{hr}$ --the air heater or the Trombe Wall?
(4 points)

Air heater produces about $90 \text{ Btu/ft}^2/\text{hr}$. Trombe Wall about $30 \text{ Btu/ft}^2/\text{hr}$.

10. Which installation is more suitable for use on existing buildings?
(4 points)

Air heater.

11. About how much time lag is there between the maximum air temperature delivered by the Trombe Wall by convection, and the maximum heat delivered by radiation?
(4 points)

About 8 hours.

12. Why is the Trombe Wall a good choice for new residential construction?
(5 points)

Its heating contribution is delivered both day and night; it is fire resistant and essentially maintenance-free.

MODULAR UNITS FOR PASSIVE
SOLAR SPACE HEATINGSLIDE #1 (Slide set title slide)

This unit provides you with guidelines and information to help you make practical use of the passive design principles you studied earlier. Two types of heaters--a Trombe Wall and a Thermosiphoning Air Heater--are discussed.

SLIDE #2 (Direct Gain)

You will also learn to calculate the net seasonal heat contribution of south-facing glazing, as well as how to estimate the proper amount of heat capacity needed to take advantage of this net heat gain.

SLIDE #3 (Sketch of sunny window)

Over the course of a heating season, south-facing glazing can provide a net heat gain any place in the United States.

SLIDE #4 (Wallasey School Diagram)

In order to use the heat south glazing gives you, thermal storage must be provided. Concrete walls can do the job, as is shown in this diagram of a school heated only by the sun, the students, and its lights.

SLIDE #5 (Winter Solar Greenhouse: Photo)

Solar greenhouses with heat storage devices are practical applications of the same principles. Notice the natural convective flow of warmed air into the living space and cooler air out to the collector area.

SLIDE #6 (Summer Solar Greenhouse: Photo)

Simple adjustment of damper controls and insulation can make these natural convection flows move to cool and ventilate a house in summer.

SLIDE #7 (Thermosiphoning Air Heater)

The thermosiphoning air heater you can build to replace conventional woodframed walls operates on just such a thermosiphoning principle. This model is compatible with conventional residential or commercial construction. It is also low in cost, and quite effective.

SLIDE #8 (Question Mark slide: Cartoon)

In order to learn the details of its construction and installation, a nearby site must be found in which the heater can be integrated into a closed structure. Then its heating properties can be well-demonstrated. You and your instructor can work this out together.

SLIDE #9 (Trombe wall winter day schematic)

A second practical fabrication task is the Trombe Wall. It serves to heat in the winter both by convection and radiation. The radiation is usually delayed by about eight hours from the convective flow.

SLIDE #10 (Trombe wall winter night schematic)

Dampers protect against drafts at night, while the day's stored heat is released to the room by radiation from the wall.

SLIDE #11 (Trombe wall summer day schematic)

The Trombe Wall can aid in summer ventilation as well. Notice the desirability of the high vents in the glazing and on the back wall.

SLIDE #12 (Trombe wall summer night schematic)

Where nights are cool, the glass and the wall can help rid the house of stored heat.

SLIDE #13 (Salesman and Customer at window)

This unit is a demonstration of a few of the practical uses of passive solar design principles. These new techniques can be very successful in the Southeast. The smart tradesperson will begin to apply them now.

REMOVING INSTALLATION BARRIERS

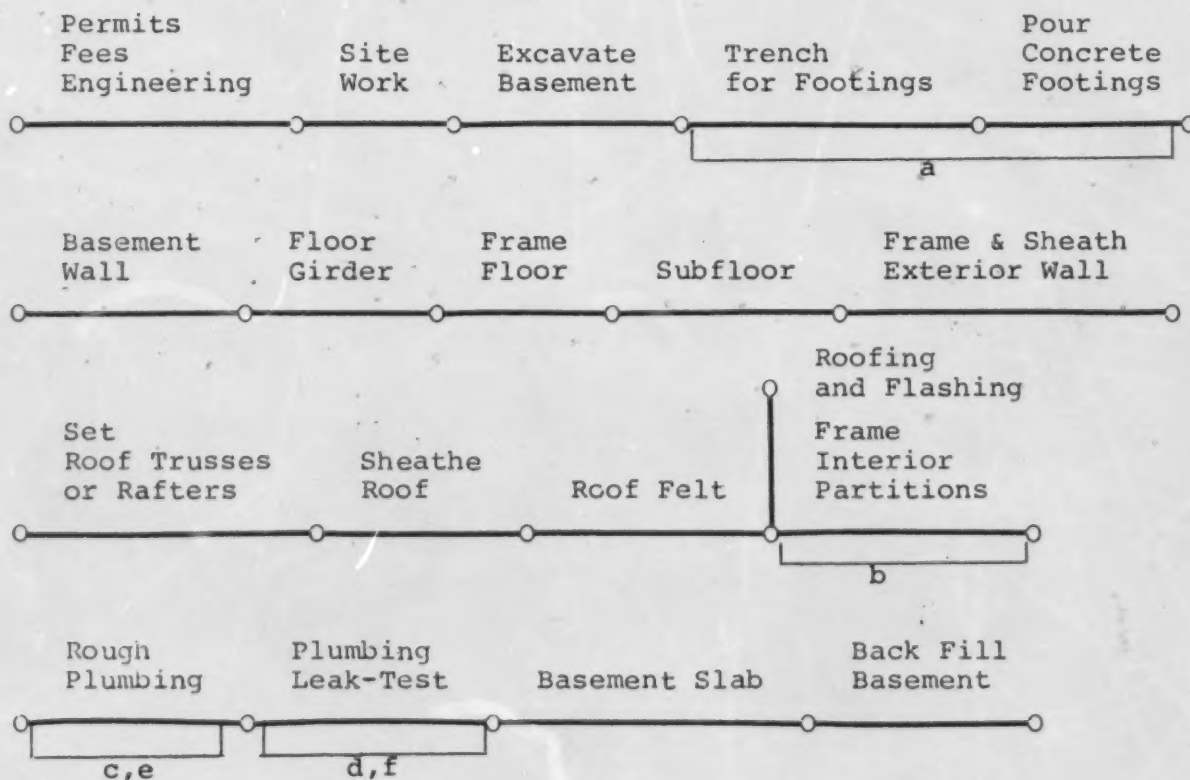
You should already understand how solar heating systems work, and their advantages, relative to conventional heating systems. It is now time to reconsider why solar systems are not more popular. One important factor is the high initial cost of the system. However, the discussion of the economics of solar systems indicated that a well-designed solar system does offer financial gains over the long run, especially in view of the rapidly inflating costs of conventional energy sources.

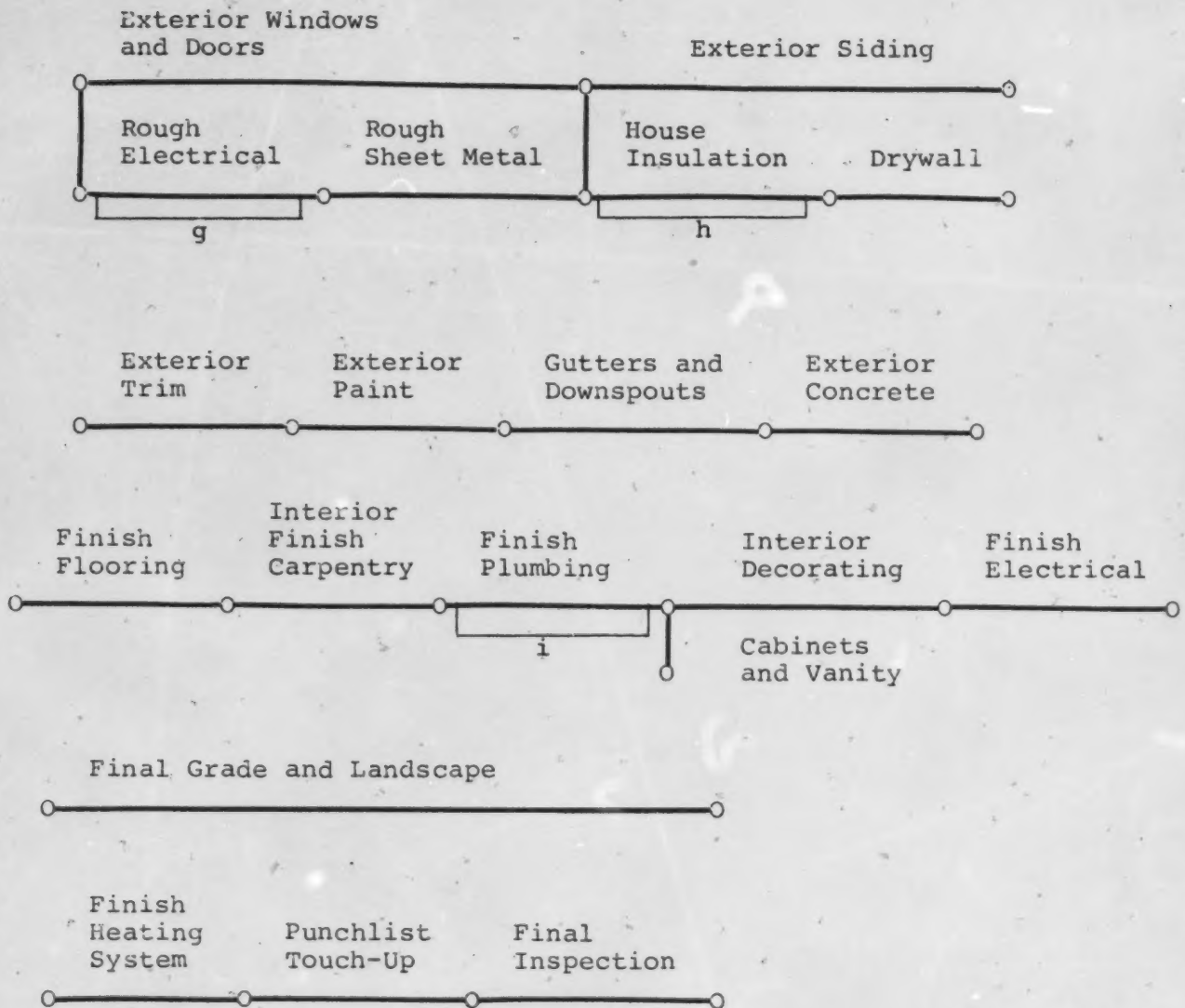
The reading for Assignment SC-2-1 suggested a variety of other factors that are barriers to solar installations. Let us now consider how we might reduce or remove these barriers. To do this, pretend you are in Atlanta visiting your State Representative. When s/he hears that you are a solar systems installer, s/he says, "Oh, that's very interesting. And how is the solar business these days?" You decide to take the opportunity to tell him/her what legislators could do to encourage use of solar energy. Assume that your Representative has some influence over the financial and insurance community, as well as over the legislative community. What recommendations would you make for legislation that might encourage solar installations and remove installation barriers? Describe your recommendations to a fellow student, and have your instructor observe your presentation.

1. legislate procedures for establishing solar easements
2. establish legislation to favor zoning and street layouts which are consistent with the requirements of solar installations
3. establish programs to educate people about the advantages of solar systems
4. legislate building and equipment codes designed specifically to set standards for solar homes and solar components
5. require financial institutions to publish their policies with regard to the financing of solar installations.

In the drawings below, indicate when each of the following procedures is performed:

- construction of storage tank structural base (for basement installation)
- placement of collectors on roof (when collectors are integrated into the roof)
- piping to equipment area
- collector loop leak-testing
- storage piping connections
- installation of control temperature sensors
- control panel installation
- piping insulation
- installation of preheat coil and domestic hot water tank





"Instructor's Materials"

UNIT SC-2
UNIT TEST

- 1) For each question, circle true (T) or false (F).
- a. T F Legislation controlling street layouts can encourage the use of solar systems.
 - b. T F The orientation of a building does not affect the ease with which collector arrays can be installed.
 - c. T F Insurance rates for solar and non-solar homes are similar.
 - d. T F Solar system building codes are readily available and contain standards specific to solar systems.
 - e. T F The local building inspector should initially be contacted when the installation is complete and ready for inspection.
 - f. T F Where local solar building codes are absent, Underwriters Laboratory certification may be required where it applies to solar systems.
 - g. T F Most financial institutions have established policies with regard to financing solar systems.
 - h. T F Most homeowners and individuals in the building construction business understand the functioning and benefits of solar systems.
 - i. T F A storage tank placed in the basement can usually be placed on the 4-inch concrete slab poured for basement floors.
 - j. T F For basement installation in new construction, the storage tank is placed before floor girders are assembled.
 - k. T F Collectors should be carefully inspected before installation.
 - l. T F Insulation is normally done before leak-testing.

- 2) After each step of house construction listed below, list the letter of the step of solar system installation that occurs simultaneously.

Steps in House Construction

Construction of basement floor d

Roofing and flashing c

Rough plumbing f

Plumbing leak-testing e

Rough electrical wiring installed a

House insulation b

Steps in Solar System Installation

- a. Control panel installed
- b. Piping insulation
- c. Placing collectors on the roof (for collectors integrated with the roof)
- d. Construction of base for storage tank
- e. Collector loop leak-testing
- f. Heat exchanger installed and piped

STEPS IN LIQUID SYSTEM INSTALLATION

SLIDE #1 (VMC Title Slide)

(Music going down under narrative)

SLIDE #2 (Title Slide)

This slide show describes two different solar systems, and the steps involved in the installation of each.

SLIDE #3 (Concrete poured basement of new house)

The first example is a system that was installed in a new house while it was being constructed. The first step in the solar installation took place after the concrete basement floor and walls had been poured.

SLIDE #4 (Hoisting storage tanks into place)

The first step in the solar installation involved hoisting the large, heavy steel storage tanks into place. The wench and boom of a tow truck were used to hoist the tanks. Since storage tanks are often large and unwieldy, they are usually installed early in new construction, and lifted directly into the basement.

SLIDE #5 (Storage tanks in place in basement)

The tanks are now in place. The hole in the top of each tank provides access for inspection and for plumbing or wiring hook-ups.

SLIDE #6 (House with steel frames on roof)

The second step in this installation occurred after the walls and roof of the house were complete. It involved preparing the roof for collector mounting. In this case, the tilt angle of the roof was appropriate to the system, so the collectors were mounted directly on the roof. On the roof are the steel frames in which the collectors will be mounted.

SLIDE #7 (Interior view of roof)

The roof has been reinforced from the inside by using spanners to distribute the weight of the collectors across the rafters. In installing collectors on the roof, it is critical that the roof be constructed or reinforced to support the weight of the collector array.

SLIDE #8 (Collector array on roof--with ladders allowing access)

The collectors are now mounted in their frames on the roof. They are manifolded together along the top and bottom of the array.

SLIDE #9 (Basement installation--DHW tank and furnace)

Once the collectors have been mounted and manifolded, plumbing is installed for connections to the basement installation. The basement installation includes the thermal storage tanks, and backup heating units including a conventional furnace and hot water heater. Control devices are also wired and tested.

SLIDE #10 (Basement installation--DHW tank and green tanks)

The plumbing is checked and leak-tested before final insulation is installed. Leaks are more difficult to detect once pipes are covered with insulation. Wet insulation can reduce system performance worse than no insulation at all.

SLIDE #11 (Basement installation--storage tanks insulated)

Finally, the storage tanks and connective piping is insulated, and the system is complete.

SLIDE #12 (Exterior view of completed collector array)

If properly installed, the solar system will provide space heat and hot water for its residents.

SLIDE #13 (House with roof with protective cover)

The second installation to be described involved installing the collectors before the roof was complete rather than on top of the roof shingles. A protective plastic sheet protects the incomplete roof from moisture during a pause in collector installation. The storage tank has already been placed in the basement.

SLIDE #14 (Copper absorber plates--close-up)

This installation involved use of Revere copper absorber plate collectors. These collectors are assembled in pieces on the roof. Here we see the installed copper absorber plate with rectangular fluid tubes. Once the absorber plate is installed, it should be covered during pauses in installation, or it may heat the roof to the point of fire.

SLIDE #15 (Copper absorber plates manifolded)

The fluid tubes are manifolded together to allow fluid to pass from the collectors to the rest of the system.

SLIDE #16 (Close-up: black absorber plate)

The absorber plate is then painted black with 3M nextel black paint. This will increase the amount of heat absorbed.

SLIDE #17 (Glazing tape on black absorber plate)

Rubber glazing tape is applied to edges of the collector frame on which the glass cover plate will sit.

SLIDE #18 (Flashing on side of absorber plate)

Leakage of the roof is prevented through use of sheet metal flashing. Butyl sealant is used to cover roof penetrations by hardware attaching the collectors to the roof.

SLIDE #19 (Roof with absorber plates)

The absorber plates are now installed and prepared for mounting of the collector cover plates.

SLIDE #20 (Men hoisting cover plates on roof)

In this case, the cover plates are hoisted individually, and carefully lifted into place. This is definitely a three-man job! When possible, it is preferable to use a crane to hoist the completed collector array, or collectors. Work on the roof can be dangerous, and should be minimized when possible.

SLIDE #21 (Basement installation)

The basement installation for this house was largely complete when these pictures were taken. The storage tank is concealed behind the white wall. This is a solar space-hot water heating system, with a backup electric hot water heater and a gas furnace.

SLIDE #22 (Incomplete control box)

This system was designed so that many of the electrical and hydronic control devices were located in a single master control area. In the lower left is a metal box containing electrical control devices. The cylindrical green tank in the center is an expansion tank, above which is an air separator. The air separator is topped by a hand valve and an air vent, on the right.

SLIDE #23 (Detail of electrical control box)

The electronics control box houses three thermostats which register and compare temperatures at different points in the system. The thermostats are mounted one above the other on the left side of the box. A staging network in the middle of the box uses the temperature information to choose the mode of system operation. Mechanical switches in the upper right allow manual control of the system components, and are used in testing the system.

SLIDE #24 (Exterior view of complete collector array)

We have now seen some of the important basic steps in two solar installations. Your next assignment will detail these steps, and will indicate precisely how they can be scheduled in new construction.

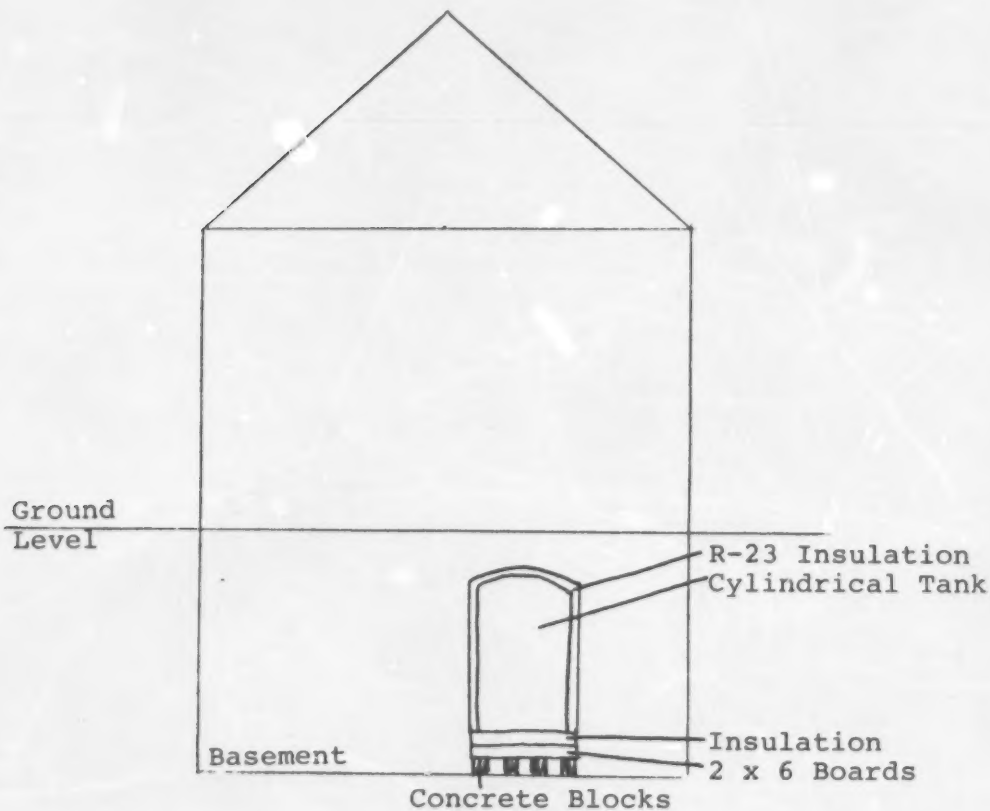
- a. List two advantages of spherical storage tanks.
- 1) cheaper to insulate
 - 2) structurally sound
- b. Spherical tanks are not often used because they are
difficult to fabricate and support.
- c. The most practical shape for a storage tank is cylindrical.
- d. What must be done to steel tanks to prevent internal corrosion?
line them with butyl rubber
- e. In considering a plastic tank, what characteristic of the tank
must be carefully noted?
its ability to withstand high temperatures
- f. Because of temperature stresses, concrete tanks require
additional reinforcement and sealing of joints
_____.
- g. The minimum useful storage tank temperature is usually at
least 90 °F.

- 1) In the drawing below, indicate how you might install a storage tank in a concrete floored basement. Indicate the following:

storage tank (its recommended shape)

storage tank base (its recommended construction)

insulation (recommended R-value)



2) Answer the questions below:

- a. What must be checked before a storage tank is installed in the attic?

The strength of the attic floor must be checked to make sure it can hold the weight of the tank.

- b. What determines the thickness of structural base that is necessary in a basement storage tank installation?

the weight of the tank

- c. Insulation of at least R- 30 is recommended for tanks placed outdoors. Insulation of R- 23 is recommended for inside tanks.

- d. Why is below grade storage tank installation not recommended?

It makes servicing and maintenance more difficult, and insulation is more vulnerable to damage by moisture.

- e. Insulation of the storage tank is completed (before, after) leak-testing.

- f. To prevent strain at tank-pipe connections, the connection can be made with a neoprene rubber hose or a bulk head connection.

- g. What is the function of shut-off valves installed in storage tank piping?

to allow isolation of the tank for servicing and repair

- h. List the steps in liquid storage tank installation:

- 1) build structural base
- 2) check tank condition
- 3) place tank on base and insulate bottom
- 4) connect piping and leak-test tank
- 5) insulate top and sides of tank

- 1) Indicate whether each of the following statements is true by circling true (T) or false (F).
- a. T F A spherical storage tank is usually the most practical shape for a storage tank.
 - b. T F Steel tanks must be lined with butyl rubber for insulation.
 - c. T F Storage tanks must withstand temperatures of at least 90° F.
 - d. T F In basement installations, the bottom of the storage tank should be placed directly on the concrete slab base.
 - e. T F In new construction, a liquid storage tank is usually installed before floor joists are built.
 - f. T F Insulation of at least R-30 is recommended for storage tanks placed outdoors.
 - g. T F The storage tank should be carefully insulated before it is filled.
 - h. T F Tank-piping connections should be made by welding the piping to its opening in the tank.
 - i. T F Even storage tanks that are located indoors must be insulated.
 - j. T F If the collector array is on the roof, the storage tank can always be supported by the attic floor.
- 2) List five steps in liquid storage tank installation.
- 1) build structural base
 - 2) check tank condition
 - 3) place tank on base and insulate bottom
 - 4) connect piping and leak-test tank
 - 5) insulate top and sides of tank

SITING SOLAR COLLECTORS

- 1) For each question circle true (T) or false (F).
- a. T F Solar collectors should be oriented to directly face magnetic South.
 - b. T F In all locations, true South and magnetic South are within two degrees of one another.
 - c. T F In Georgia, true South may be estimated by first determining magnetic South.
 - d. T F All building roofs are constructed to be able to support collector arrays.
 - e. T F Local building codes sometimes restrict collector array sites.
 - f. T F The collector array can be sited without consideration of where other system components will be located.
- 2) Fill in the blanks with the correct answer:
- a. The relation between true South and magnetic South can be seen in a map published by the U. S. Geological Survey.
 - b. Trees and building near a prospective collector site must be considered in choosing a site because they might shade the array.
 - c. Five factors which must be considered in siting collectors are:
 - 1. site orientation
 - 2. weight and size of array
 - 3. roof strength
 - 4. aesthetic impact
 - 5. possible shading by trees or buildings
 - 6. insolation received
 - 7. local building regulations
 - 8. ease of maintenance and repair
 - 9. ease of locating rest of system relative to array.

- d. Solar collectors must be oriented to face true
South.
- e. A collector array should be sited to receive sunlight
for 8 hours a day, centered around solar
noon.
- f. A legal agreement which guarantees the solar homeowner's
right of access to sunlight is called a solar
easement.
- g. The appropriate tilt angle for a solar space-heating system
is latitude + 15°.
- h. Two factors critical to choosing the appropriate collector
tilt angle are: local latitude and system function.

ROOF MOUNTING OF COLLECTORS

1. Fill in the blanks with the correct answers:
 - a. Three basic considerations to be kept in mind when mounting collectors on the roof are:
 1. determine the roof has adequate load-bearing capability
 2. leak-proof the roof
 3. insure collector resistance to adverse weather conditions.
 - b. Building structural requirements for your area can be found in local building codes.
 - c. Rack mounted collector installations must be designed to be particularly resistant to weather conditions of high wind.
 - d. Collectors must be mounted on racks when roof angle or orientation is unsuitable.
 - e. Two procedures used to prevent roof leakage are use of silicone OR roofing and flashing.
sealant cement.
 - f. In new construction, if roof tilt angle is suitable, the collectors may be mounted on an incomplete roof after roof felt has been laid.
 - g. Pitch pot mounts are used with flat roofs.
 - h. Two types of washers which are used on the bolt or lag screw which holds the collector mounting brackets to the roof are galvanized and neoprene washers.
 - i. Two possible problems if collectors are mounted directly on top on roof shingles are fire and roof rotting.
 - j. If roof angle is suitable, but it is not desired to mount the collectors directly on the roof, the collectors are mounted on stand-offs.
 - k. If major adjustments in roof tilt angle must be made, collectors are mounted on racks.

2. Draw a cross-section of a collector mounting directly on top of an existing roof. Indicate the following:
 - a. location of sheathing and shingles
 - b. location of mounting block
 - c. where sealant is applied
 - d. where flashing is applied
 - e. how the collector fits into the mount

See Information Sheet SC-4-2, Figure 1.

GROUND MOUNTING OF COLLECTORS

1. List preventive measures for avoiding the problems below associated with ground mounting of collectors:

<u>Possible Problem</u>	<u>Preventive Measure</u>
1. People being burned by collector or piping.	1. Insulate piping, fence in collector.
2. Vandalism.	2. Fence in collectors.
3. Damage to collectors by falling objects.	3. Place wire net above collector.
4. Entry of insects into house through system wall penetrations.	4. Carefully seal penetrations.

2. Identify each statement as true (T) or false (F).

- a. T F Ground mounting supports should be established above the frost line.
- b. T F Footings should include a minimum of ½-inch diameter threaded rod anchor.
- c. T F The collector bottom edge should be two feet above the ground.
- d. T F Collector weep holes should be sealed tight when collectors are ground mounted.
- e. T F Wood footings are often used for ground mounting.

1. For each statement, circle true (T) or false (F). (3 1/3 points each.)
 - a. T F In Georgia, true South and magnetic South are the same.
 - b. T F Solar collectors should be oriented to face true South.
 - c. T F Before roof mounting collectors, it is important to determine that the roof can bear the weight of the collectors.
 - d. T F In roofs being constructed, the collectors are mounted on top of the roof felt.
 - e. T F In retrofit systems, if roof angle is appropriate, the collectors should always be mounted directly on top of the shingles.
 - f. T F Pitch pots are used with tilted roofs whose tilt angle is almost optimal for the collectors.
 - g. T F Supports for ground mounting must be established above the frost line.
 - h. T F Spanner mounting is used when there is no access to attic space.
 - i. T F Mounting bolts for spanner mounts are installed directly above the rafter.
 - j. T F Lag screws should penetrate at least 2-inches into the rafters.
2. Fill in the best answer(s) to complete each statement.
 - a. True and magnetic South are indicated on U. S. Geological Survey maps. (3 1/3 points.)
 - b. Collector arrays must be sited to receive a minimum of 8 hours of sunlight. (3 1/3 points.)
 - c. A solar easement is: a legal agreement granting access to sunlight. (3 1/3 points.)

d. Four factors to be considered in siting collectors are:
(3 1/3 points each.)

- insolation available at the site
- the ability of the site to support collector weight and size
- the orientation of the site
- local building codes which restrict sites
- aesthetic impact
- accessibility of site for maintenance and repair, and for locating other system components

e. Three basic considerations when mounting collectors on the roof are: (3 1/3 points each.)

1. be sure the roof has adequate load-bearing capability
2. be sure the roof remains leak-proof
3. be sure the roof installation is resistant to severe weather conditions.

f. Roof leakage through lagscrews penetrating the roof is prevented by covering the screws with roofing cement

(3 1/3 points.)

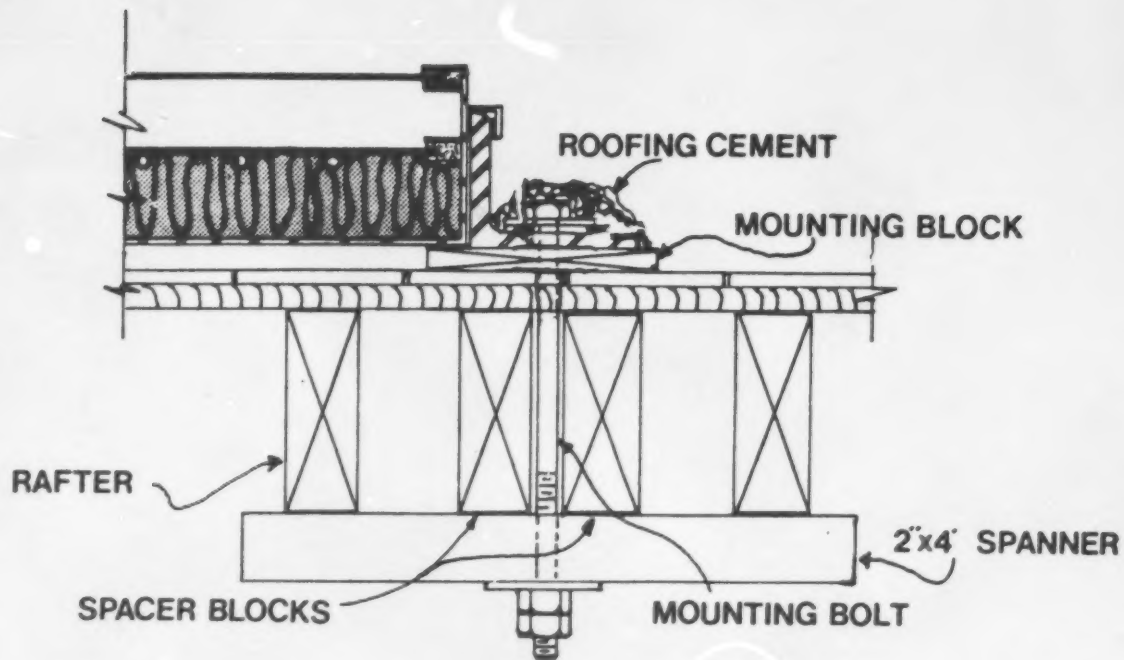
g. Ground mounted collectors are sometimes fenced in to: protect people from being burned by them, protect them from vandalism

(3 1/3 points.)

h. Lag screws used in lag screw mountings should be at least 1/2 inch in size. (3 1/3 points.)

3. In the spanner mounting detailed below, label the following:
(3 1/3 points each.)

mounting block
mounting bolt
spacer blocks
spanner
rafter
roofing cement
nuts



Answer the study questions below:

- a. An important part in planning the solar installation so that you will know how every component fits together is to draw a diagram of the system layout.
- b. Another important step prior to beginning the actual installation so as to prevent costly delays is to gather all necessary materials and equipment.
- c. In the Lennox installation system, collector supports are attached by nailing directly to the vertical boards attached to the roof. These vertical 2x4 boards are designated as sleepers.
- d. The vertical 2x4 members are nailed directly to the roof trusses and are covered with sheet metal flashing. What is the purpose of the sheet metal flashing? to limit the possibility of roof leaks.
- e. The members placed horizontally across the vertical members are called supports. What type of wood and what size is recommended for the top support of the top row and the bottom support of the bottom row? Redwood 2 x 10's
- f. Although it is not explained in your reading assignment, can you think of a reason why a particular type of wood is specified for the collector supports?

A wood not readily subject to rotting from moisture or from insect damage is required for long life.
 Note: Cedar, cypress or pressure treated wood could be used in place of redwood.
- g. What determines the vertical spacing distance of supports?

The length of a collector and the amount of gap desired between rows.
- h. What is the minimum suggested distance between collector rows?
6-inches
- i. Your reading assignment does not explain the reason for leaving a gap between rows. Do you know what this space is for?

To allow room for plumbing the collectors.

- j. What is the minimum number of persons required to manually raise a collector to the roof and position it on the collector supports? two
- k. A specially designed triangularly shaped angle iron tool with a pulley attached is described for pulling the collectors to the roof supports with a rope. How is this tool designed to be held on the roof while pulling up a collector?

It is designed to fit snugly over a two-inch thick board and it is placed over the top collector support of the collector being raised.

- l. What prevents the collector from tearing loose shingles or snagging on the collector supports while it is being pulled to the roof?

A ladder is used under the collector as a runner. The collector slides along the smooth ladder rails.

- m. True False -- The collector must be installed with the flow tubes running in a horizontal direction.
- n. True False -- Because all other collectors in a row are set in relation to the first one installed, the left most collector in the row is set first.
- o. True False -- It is important that the first collector set in place does not deviate more than one degree from level.
- p. True False -- The collector is temporarily held in place while it is being leveled by nailing a small brace board to the bottom support.
- q. True False -- Collectors are covered after installation and remain covered until put into operation to prevent overheating the "dry" collectors.
- r. After leveling and fastening the first collector in position, how do you determine that the next collector is properly aligned/leveled?

Use a spacer of proper thickness to set the distance between the first collector frame and the next collector frame near the top and near the bottom to assure equal spacing. Then fasten the collector in position. Repeat for all other collectors in the row.

- s. True False -- The purpose of spacing between collectors is to allow thermal expansion.
- t. True False -- The recommended spacing between collectors is 1/16 to 1/8 inch.

Answer the study questions below:

- a. Why is it best to avoid the use of high pressure rubber hoses to attach the manifold to pipes or to collectors?
Hoses will deteriorate over a period of time.
- b. Where must an air vent valve be installed in the system?
at the highest point
- c. What is the purpose of the air vent valve?
to remove air from the piping circuit
- d. Three possible array circuits which can be used are:
 1. parallel flow - direct return
 2. parallel flow - reverse return
 3. series flow
- e. Why are parallel flow-direct return circuits not usually used?
high pressure drops along the supply/return manifold cause flow in balance
- f. True False -- A parallel flow-direct return circuit is easily balanced if a manual valve is placed in the return manifold at each collector connection.
- g. True False -- Series flow is used when a higher output temperature from the collector system is desired.
- h. True False -- In large planar arrays more piping is required for headers and manifolds than would be required with a parallel system.
- i. True False -- In a properly designed system using parallel reverse flow, balancing is seldom required since flow through each collector is the same.
- j. True False -- Open loop systems are normally used only where sub-freezing temperatures are rare.
- k. Open loop systems must have provisions for draindown in freezing or near freezing weather. To insure adequate drainage, what should be the pitch in horizontal piping runs?
1/4-inch per ten feet -- Note: Some installers consider the book answer to this question to be inadequate. They recommend a minimum pitch of 1/8-inch per foot of horizontal piping to assure complete drain down.

- l. What type of system is normally used in cold climates?
closed loop

- m. What is the major difference between a closed loop and open loop system?

The closed loop system uses a heat exchanger. The fluid flowing through the collectors does not go to storage. In an open loop system, the fluid flowing through the collectors also flows to storage.

- n. True False -- An advantage of the closed loop system is that the amount of antifreeze required is small since only the fluid in the collector-heat exchanger loop must be protected from freezing.

- o. The purpose of an expansion tank in a closed loop system is to provide a place for fluid expansion without
increasing system pressure

- p. Piping should be sized so that water velocity does not exceed 5 feet per second.

- q. How can you prevent electrolytic action between dissimilar metal pipes which must be connected?

Use a dielectric union or a short rubber hose between pipes.

Answer the study questions below:

- a. In a closed loop system the collector manifolds not only join the collectors to each other, but also join the collectors to the loop through the heat exchanger.
- b. True False -- Two qualities of outside plumbing are neatness and shortness of runs.
- c. True False -- Circuit isolation and component servicing are facilitated by providing adequate shut off valves and unions.
- d. True False -- Throttling valves should be installed upstream of a fixture whenever possible.
- e. True False -- Piping should be sized for high velocities to decrease pumping requirements.
- f. True False -- Piping should be pitched up to 1/16 to 1/8 inch per foot to facilitate drainage.
- g. True False -- Exit ends of drain pipes must be threaded.
- h. Minimum velocity for downcomer pipes should be at least 2 feet per second.

1. Before beginning this exercise, be certain that (a) all students are familiar with the fundamentals of lighting and adjusting the oxy-acetylene torch and (b) all students are familiar with brazing and hard-soldering techniques for copper and brass.
2. After step #16 on Job Sheet SC-5-1, check student work and observe the following points:
 - (a) The two hose barbs are well aligned vertically.
 - (b) That they are properly spaced (36-inches on center).
 - (c) The two copper end caps are completely seated in/on tube.
 - (d) Check brazing and soldering for excess material.
 - (e) Check for cracks and/or incomplete fill of joints.
 - (f) Assess overall quality of soldering and brazing.
 - (g) Give student a pass or no pass to complete testing under 100 psi pressure.
3. At step #23, check student set-up for the following:
 - (a) Correctness of hook-up of air hose.
 - (b) Tightness and position of all hose clamps.
 - (c) Isolation from other personnel in laboratory.
 - (d) Plastic, plywood, metal or other shields should be placed around set-up to prevent any flying parts from reaching other sections of the work area.
 - (e) Instruct student to proceed or make necessary changes.
4. After step #24, observe:
 - (a) Student to be sure he keeps his body clear of the bolt and short hose and the attached air hose.
 - (b) Student's application of soap solution and observation of all potential leak area.
 - (c) Student's release of air pressure in system.

Answer the study questions below:

- a. True False -- It is not important that air vents be exactly vertical to operate properly.
- b. True False -- Piping runs are braced by the collector supports to add stability and neatness to the installation.
- c. After completing piping runs through the roof jack and insulating the pipes, the roof jack should be filled with tar.
- d. True False -- The purpose of filling the roof jack is to limit leakage possibilities.
- e. How is the hole size to be cut through the roof determined?
With two pieces of pipe insulation placed side by side
- f. How thick is the foam insulation that is placed around the pipes? 3/4-inches
- g. How is the insulation placed around the pipes? by splitting in a straight line
- h. How are the split pieces of insulation put back together?
with glue or insulating tape

1. Before beginning the exercise, students must either fabricate the roof jacks or they must be fabricated for them. Pages 9-10 of Fundamentals manual suggests use of a vent pipe flashing fitting. Your school may prefer to use these for this exercise.
2. Check neatness of hole cut through roofing and sheathing.
3. Check nailing of flashing and sealing of edges.
4. Check pipe and insulation fit through hole.
5. Allow student to fill with tar or roofing cement or ask student to redo work.

EXAMINATION OF A SOLAR COLLECTOR INSTALLATION

In this exercise, you will make a step-by-step examination of an assembled solar space heating or hot water system at your school. You will examine with your instructor the collector array and the associated plumbing and answer the questions as listed.

IF THE SYSTEM IS OPERATIONAL, BE CAREFUL NOT TO TOUCH HOT COMPONENTS!

Equipment: Inclinator, tape measure or pocket ruler or protractor

Notice the number of collectors in the array.

Notice the angle at which they are tilted and the method used for supporting them. If possible, measure the angle of inclination; if not, ask your instructor for the angle.

1. Based on the angle, what is the system set up for?

Angle same as latitude for hot water. Angle up to 15° greater than latitude setup for space heating.

If there is no flashing or trim between collectors, note the spacing. If it is covered you may not be able to see this.

2. What is the purpose of spacing between the collectors?

Room for thermal expansion.

Note the direction the liquid tubes are running in the collectors.

3. Are the collectors set up with the flow tubes located properly?

Yes, if tubes are running vertically.

Note the incoming piping, the inlet and exit headers (manifolds).

4. What is the circuit arrangement?

Answer depends on system setup. Will most likely be parallel flow-reverse return. However, the system could be hooked-up otherwise.

Note the manifold-to-collector connections. Are they made with silicone rubber hose or flexible copper tubing?

5. What is the purpose of the offset and bend in the manifold-to-collector connection?

To provide flexibility for expansion.

Note the number of air vents and their location.

6. What is the correct location for an air vent?

At the highest point in the piping run to allow escape of entrapped air.

Note the return pipes and the building penetration. What type of penetration and sealing technique is used?

Instructor must answer this question depending on setup at his particular school.

1. Collectors must be inspected when they arrive on site.
List items to look for in examining collectors.
 - a. Bent casings
 - b. Cracked cover plates
 - c. Imperfections in the absorber surface coating
 - d. Improperly installed rubber plate mounts
 - e. Missing parts

2. The purpose of keeping a collector covered prior to the time it is put into operation is to avoid high temperatures inside dry collectors.

3. The best and safest method of hoisting collectors to the roof is to use a crane.

4. What is a closed loop system?

A system requiring an antifreeze solution and a heat exchanger circuit to prevent toxic liquids from mixing with the potable water supply.

5. Where are closed loop systems generally used?

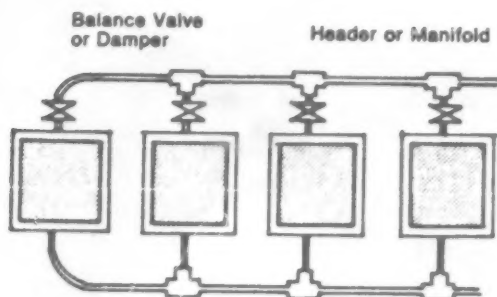
In climate with near freezing and sub-freezing temperatures.

6. An open loop system uses water from the cold water supply and circulates it throughout the system. How is this system normally protected from freezing?

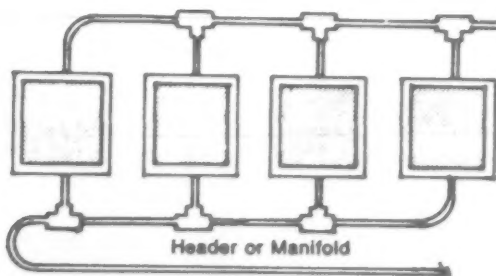
It must have automatic provisions for completely draining pipes and collectors during periods of near freezing and sub-freezing temperatures.

7. Draw schematically:

a) a parallel flow--direct return system



b) a parallel flow--reverse return system



8. Why is the parallel flow--reverse return system preferred?
It is much easier to balance.
9. How do you minimize electrolytic action when two dissimilar metal pipes have to be coupled?
Use a dielectric union on a short section of silicone rubber base.
10. The final step after installing outside piping is to
completely insulate it

Answer the study questions below:

The primary system you will be studying as a model for installation in this unit is the closed loop system. However, there will be many installations, particularly in the Southern states, where open loop systems will be used. It is important that you understand the difference between the two systems and how installation procedures differ.

- a. T F "Closed loop" means the heat transfer fluid flows through the collectors, through a heat exchanger and an air separator, and is then pumped back to the collectors.
- b. T F In a closed loop system the storage water is pumped from the bottom of the tank through the heat exchanger and back to an opening near the top of the tank.
- c. T F In the heat exchanger, water from the collectors mixes with a portion of the water from storage to raise the temperature of the storage water.
- d. T F Closed loop means that there are no air vents in the loop from collectors to heat exchangers and back.
- e. T F In an open loop system, water is used as it comes from the cold water supply system of the building and is circulated throughout the entire circuit.

Note: The previous reading assignment utilizes the term expansion tank, while Figure 9-15 shows two compression tanks in the two loops. These are the same items.

- f. In a closed loop system, water in the collectors and the outside loop is kept from freezing by mixing antifreeze with the water.
- g. Where is a convenient place to add antifreeze in the collector-heat exchanger loop?
in the expansion/compression tank
- h. What is the main purpose of the expansion/compression tanks shown in both loops of the closed loop system?
to allow the thermal expansion of the liquid in the loops
- i. What is the recommended pressure head on the intake side of the pumps?
five feet of water

- j. How does the requirement of the previous question affect the location of pumps and storage containers in the load side loop?

Pumps should be placed below storage whenever possible.

Answer the study questions below:

- a. The figure on page 35 (Lennox Solar Manual) shows a completed collector fluid loop(inside). The initial step in plumbing the inside portion of the collector fluid loop is _____
_____ to mount the major components on the wall _____.
- b. The collector fluid loop (inside) is also given another name. What is this name?
glycol loop (inside)
- c. After marking location of components on the wall and constructing and installing brackets the next step is to install and _____ level _____ the major components.
- d. What major component is placed at the highest point in the collector fluid loop (inside)?
the compression tank
- e. T F If the heat exchanger is marked as to inlet and outlet sides, it makes no difference which way it is installed.
- f. Why are purge lines located outside the structure not insulated?
Their purpose is to dump excess heat.
- g. What must be installed in the line when there is a transition from copper pipe to an iron component?
a dielectric fitting
- h. How do you "isolate" main components in a loop?
by installing valves on either side
- i. What is the name of the line that runs through a cross-fitting from the compression tank fitting to a hose faucet?
fill line
- j. T F In the parallel "Z or reverse" flow piping arrangement, only one supply line is required regardless of the number of rows of collectors.
- k. The valve installed in each collector supply line to regulate flow is known as a balance valve .
(circuit setter is another answer)

Answer the study questions below:

- a. T F The guidelines for installing domestic water heating systems differ drastically from those for space heating systems.
- b. T F Local building codes safety measures may affect installation requirements to protect the potable water supply.
- c. What is the maximum collector pressure rating?
50 psi maximum
- d. T F The main storage tank should be placed directly on the floor for stability.
- e. What type of pump is suitable for the fluid loop in a closed loop system?
cast iron
- f. Name two things that can be done to decrease the load on the pump.
 - 1) maintain pressure in the system
 - 2) use as few fittings as possible
- g. List the major components found in a domestic hot water typical collector fluid loop (inside)?
pump, air scoop/expansion tank, air scoop vent, temperature and/or pressure indicator, expansion tank relief valve, balance valve, check valve, drain valve, fill valve.
- h. What materials are acceptable as antifreeze?
 - 1) ethylene glycol
 - 2) propylene glycol

2. Where was the heat exchanger located?

In most cases, it is going to be in the storage tank.

3. What is the purpose of the expansion tank?

to allow expansion of the hot fluid in the circuit

4. If the particular system you examined did not have an air separator, how does entrapped air get out of the system?

Venting takes place at the top of the system.

5. What is the purpose of the check valve located in the line between the collectors and the heat exchanger?

to prevent thermosiphoning if tank temperature (heat exchanger temperature) exceeds collector temperature

6. What is the purpose of the balance valve?

to regulate the flow of fluid through the collectors

7. If you did not find a balance valve in your circuit, what does it tell you about your system?

It was engineered as a package to provide proper flow control.

8. If the glycol loop loses fluid, where and how can you refill it?

There should be a fill valve near the top of the collector and/or a fill line somewhere in the plumbing loop. On the Lennox System, it is filled at a quick-connect connection to the heat exchanger.

Answer the study questions below:

- a. What is the first step in installing load side loops?
mounting or placing major components
- b. What are the major components of the load side loop.
 - 1) the storage tank
 - 2) solar space heating coil
 - 3) heat exchanger and solar coil pumps
 - 4) hot water pre-heat coil
- c. What material is used for the domestic hot water preheat coil?
3/4 inch soft, copper tubing
- d. How is the preheat coil formed?
The tube is filled with sand and is bent around a six-inch diameter pole.
- e. What type of fitting is used to hold the preheat coil in the tank?
compression type
- f. When is insulation applied to the storage tank?
after all pipe fittings are installed
- g. Where on a conventional furnace is the solar heat coil placed?
between the return air cabinet and the furnace
- h. Where should you mount the pumps which circulate hot water between storage and the solar heat coil?
on the wall in the same manner as the components in the glycol loop
- i. Where is a manual bleed valve placed in the load side loop?
in the highest piping runs

- a. Two valves located on the storage tank which are part of the load side loop are:
 - 1) potable tank drain
 - 2) temperature/pressure relief
- b. The valve connected to both the line from the storage tank and the cold water line is the mixing or tempering valve.
- c. What is the purpose of the valve described in question (b)?
to drop storage water temperature down to the temperature of the water in the conventional hot water tank
- d. Was there a pump in the load side loop? NO
- e. Why is no pump needed in a system designed to supply hot water only?
Pressure on the cold water supply system replaces the water drawn off through the conventional hot water tank.
- f. Space heating systems have two pumps in the load side circuit. What is the purpose of each pump?
 - 1) One circulates water from storage through the heat exchanger with the collector fluid loop and back to storage.
 - 2) The other circulates hot water from storage to the solar heat coil in the conventional furnace and back to storage.

1. T F Local codes may affect the type of heat exchanger and the valving required to protect the potable water supply.
2. T F It makes no difference which openings are used for inlet and outlet connections on shell and tube heat exchangers that are not specifically marked.
3. T F The compression tank should be located at the lowest point in the collector fluid loop (inside).
4. T F Purge lines outside the building are not insulated since heat loss is desired when fluid is circulating in these lines.
5. T F The only component of the collector fluid loop (inside) that should have an air space is the compression tank.
6. T F In the closed loop system, the line running from a hose faucet through a check valve to a cross fitting below the compression tank fitting is called a fill line.
7. State two purposes for the expansion tank in the collector fluid loop.
 - 1) Provides a place for the fluid in the circuit to expand without increasing the pressure of the liquid in the system
 - 2) Provides a handy opening for the adding of antifreeze
8. Explain the difference between an "open" and a "closed" loop system.

In an open-loop system tap water is circulated throughout the entire circuit. The water in storage also circulates through the collector.

In a closed-loop system, the fluid in the collectors circulates through a heat exchanger and back to the collectors. Storage water circulates through the heat exchanger and back to storage through a separate loop.

9. How does the closed loop system reduce the cost of anti-freeze?

Antifreeze is only required for the collector-heat exchanger loop and not for the large quantity of storage water.

10. What mechanism is used to prevent freezing in an open-loop system which is circulating tap water?

Provisions are made to automatically drain the outside components of the system during freezing or near-freezing weather.

11. What is the flow rate in feet per second for a one-inch pipe carrying 15 gallons per minute?

5.57 fps

12. What should be the operating pressure of the temperature pressure relief valve mounted in the top of the storage tank?

125 psi

13. Where should a vacuum relief valve be installed?

above the cold water inlet of the tank

14. Why is a check valve required in the line between collectors and the heat exchanger in the storage tank?

to prevent thermosiphoning when tank temperatures are higher than collector temperatures

15. What is the purpose of a circuit setter?

to balance flow

Answer the study questions below:

1. In wiring the control system, what determines such things as the gauge of wire necessary, the size of fusing and where conduit is needed?

Local electrical codes

2. In the Honeywell Control System, the control panel chasis contains the following items:

- a. differential controller
- b. collector setpoint potentiometer
- c. switching relays
- d. toggle switches
- e. transformer
- f. terminals for wiring connectors

3. Besides accessibility and temperature considerations, what should determine the control panel location?

The length of wiring runs to sensors, aquastats, disconnects and switches.

4. The collector sensor is clamped as close to the collector outlet as possible. To prevent sunshine from impinging directly on the sensor where should it be clamped?

To the underside of the top manifold

5. How is the sensor wiring routed through the collector?

Through the insulation and out a condensate drain hole at the bottom

6. Where is the remote sensing bulb for the purge aquastat control mounted?

To the fluid return line from the collectors

7. Where is the storage sensor installed?

In an immersion well near the bottom of the storage tank

8. Where is the storage aquastat installed?

In an immersion well near the top of the storage tank

9. To what control inside the control panel are the storage sensor and the collector sensor wired?
the differential controller
10. The control valve which directs fluid to the solar coil or the storage tank is connected electrically via the control panel to three temperature sensors. What are these sensors?
- a. collector sensor
 - b. storage sensor
 - c. thermostat
11. A dual-control valve is installed in the collector fluid loop return line and connects to the lines feeding the purge coil. It is connected electrically to the purge
aquastat and the control panel.

Answer the study questions below.

1. Grounded metallic conduit and shielded cable wiring should be used for wiring electronic sensors to minimize what possible problem?
radio frequency signal interference
2. Where must the shield be connected to ground?
at the control panel
3. For runs exceeding 100 feet from sensor to control panel, what size wire must be used?
No. 14
4. The control panel must be wired to a 120V AC, 60 hz, 30 amp power supply with overload protection and disconnect means as required by local code.
 - a. Which power supply wire attaches to terminal L1?
hot/black
 - b. What wire goes to terminal L2?
neutral/white
5. The solar panel sensor and the storage sensor are wired to the differential temperature controller. Which pressure contacts are used for:
 - a. The solar panel sensor? F, G
 - b. The storage sensor? E,F
6. The purge aquastat controller is wired to what pressure points?
5AQ and L1
7. The storage aquastat control is wired to what pressure points?
2, 5, and 7
8. The return air limit control is wired to pressure points FL and L1 which allows it to control valve 2.
9. Pumps P1 and P2 always operate together. Follow the wiring diagram. What turns these two pumps on or off?
the differential temperature controller

10. Pump P3 allows what mode of heating to heat the house?
heating from storage
11. The space thermostat is connected directly to four terminals on the control panel. What are the four terminals?
1, 2, 3 and 4
12. What other components may be connected directly to the thermostat?
the 24V transformer, the four-speed relay, and the cooling contactor
13. If the thermostat is used to control heating, only a jumper should be connected between what two points on the thermostat?
RH and RC
14. The fan control and motor are connected to what terminals on the control panel?
FS and FS
15. If a two-pump, three- or four-valve system is installed, how must the control panel be changed?
A jumper must be placed between contacts Y and Z.
16. In the two pump, three- or four-valve system, where are valves 3 and 4 connected?
at P3 and L2

1. What is the first step required before any electrical wiring and component installation is ordered?
check local electrical codes
2. What is always the first step prior to making any electrical hook-up?
disconnect main power supply to panel on which you are working
3. The second step should always be...
to check across every power terminal and each terminal to ground with a meter or test lamp to be positive all power is off
4. The type of control that compares the difference in temperature between collector and the storage tank and turns on or off the collector fluid loop pump is the differential controller.
5. The two devices which provide input data to the differential controller are:
 - a. the collector sensor
 - b. the storage sensor
6. The electronic sensing device that provides the signal to operate the dual control valve so that excess heat is diverted away from the collector(s) and storage is called the purge aquastat.
7. What two control devices must activate to provide signals so that fluid can flow through the solar heat coil from storage when no energy is available from the collectors?
 - a. The storage aquastat
 - b. The space thermostat
8. The Honeywell Model W986A Solar Control Panel, a typical solar control, can be used to control two types of solar hydronic systems. What are these two types?
 - a. 3 pump -- 2 valve
 - b. 2 pump -- 4 valve
9. The Honeywell Model W968A Solar Control Panel contains switching relays, manual switches, field wiring terminals, and indicator lights. There are three main components besides those listed above. What are these components?
 - a. differential temperature controller
 - b. transformer
 - c. collector set point potentiometer

10. How can the difference in temperature on the differential control be changed?
by changing the on-off plug in resistors and sensor connections
11. How does a temperature sensor (thermistor) work?
The electrical resistance of the unit changes with temperature.
12. How does an aquastat sensor work?
expansion or contraction of gas in the bulb causes a diaphragm to open or close contacts
13. What is the purpose of the return air limit control located between the solar heat coil and the blower of the auxiliary heat furnace?
to direct water flow to the storage tank when the temperature exceeds 140° F
14. If pump operating amperage and voltages exceed the rating of the control equipment, what must you do?
add another relay for the extra current and voltage

1. T F There is only one specific time in the installation procedure when insulation should be applied to the pipes.
2. T F Since water is used to flush the system, it is the most convenient medium for leak-testing.
3. T F Water is more likely to leak out of the system than is an ethylene glycol water mixture.
4. T F A single flushing of the system is sufficient.
5. T F Before beginning the filling operation, all valves in the collector fluid loop should be open except the valve in the drain line.
6. T F All toggle switches inside the panel should be in the "on" position.
7. T F The pressure relief valve can be capped to raise the system pressure to 50 psi for a better check during leak-testing.
8. T F For quicker bleeding of air, the stems of automatic vents can be depressed intermittently.
9. T F The purge lines and coil are filled by energizing valve V1.
10. T F After filling to desired pressure, the system should be drained. Leaving air vents closed will expedite the draining.
11. T F After refilling the system and energizing the purge valve, pump P1 should be energized and water circulated for two hours.
12. There are two ways to check for leaks. One is a visual inspection of all soldered joints. What is the other?
observing the pressure gauge for a decrease in pressure
13. T F After draining the system and repairing any leaks there is no reason to refill system to check the repaired areas.
14. After satisfaction with soundness of the system, the final three steps after draining are:
 - a. Change filter cartridge
 - b. Uncap pressure relief valve
 - c. Close drain line faucet and gate valve

Answer the study questions below.

1. The first step in preparing to charge the collector fluid loop is to preset circuit setters to calculated degree opening.
2. T F The fill mixture for the collector fluid loop should be 50-50 ethylene glycol-water. NOTE: The manual does not so state, but the water used in charging the collector loop should be distilled water.
3. What causes the system pressure to drop from the desired 12 psig after filling the system?
dissolved air in the fluid
4. After system pressure is stabilized, how is final flow balance accomplished?
with a pressure differential meter attached to the circuit setters

Answer the study questions below.

1. T F Before beginning flushing and charging up the load side loops, power should be available to the control panel and all switches inside the panel should be in the "stop" position.
2. T F All valves including gate, globe, air vent and circuit setters in the load side loops should be open.
3. After filling the storage tank, what steps besides bleeding air are necessary to fill the heat exchanger to storage loop?
energize pump P2 and valve V2
4. Other than bleeding air, what step is necessary to fill the heat exchanger to space heating loop?
de-energize valve V-2; pump P2 is still running
5. What steps are necessary to fill the storage to space heating loop?
de-energize pump P2, energize pump P3, bleed air from pump P3 and from manual bleed valve
6. The storage tank, water heater and most of the plumbing is drained by opening the drain valves on the two tanks. What is necessary to drain the solar heat coil?
remove the drain plugs
7. What is the approximate time necessary to circulate water in each loop after refilling to properly leak test the load side loops?
30 minutes
8. What component is useful in determining the proper fill level for the storage tank?
the sight glass
9. T F One of the final steps in preparing the load side loops for operation is to set the tempering valve for the desired hot water temperature.
10. T F Balancing of the circuit setters is accomplished in the same manner as with the collector fluid loop.
11. T F The final step after setting and adjusting all controls is to uncover the collectors.

UNIT TEST
UNIT SC-8

1. What must be done to the collectors before putting any fluid into the collector fluid loop?
the collectors must be covered
2. If the requirement answered by question #1 is not accomplished what may happen?
 - a. fluid can reach dangerously high temperatures
 - b. collectors may be damaged
 - c. personnel may be injured
3. How many times should the system be flushed before final charging? twice
4. When should leak-testing be completed?
during the second filling
5. Most homes in metropolitan areas built in the last fifteen years have the water line regulated to 50 psig. What must be done to utilize this full pressure in leak-testing the system?
The pressure relief valve in the loop must be capped, otherwise it will open at 30 psig.
6. If water pressure greater than 50 psig is available, should it be used for testing? Why or why not?
No, collectors are designed for 50 psig maximum. More pressure than this might damage the collectors.
7. During leak-testing, how long should water be circulated?
approximately two hours
8. Name two indicators of leaks in the system.
 - a. visual observation
 - b. a decrease in pressure on the gauge
9. What is required to properly balance the flow through a circuit setter valve?
a pressure differential meter
10. What is the minimum length of time the pumps should be run to check for leaks in each of the load side loops?
30 minutes

11. What does setting the collector set point potentiometer at 90° F mean to the operation of the system?

This is the minimum fluid temperature the system will accept from the collectors for direct heating of the house.

12. After all controls and wiring have been thoroughly checked out and all switches are in the "auto" position, what is the final step to putting the system in operation?
- uncover the collectors

Answer the study questions below.

1. While inspecting collector cover plates, what items are you looking for?
dirt, dust, condensation, chips, cracks and deteriorated rubber seals
2. In visually inspecting the absorber plates of a closed-tube liquid collector, two items should be looked for. What are these?
 - a. Condition of absorber plate--there should be no scratches or peeling coating
 - b. Tubes--should not be loose or have pulled away from the plate
3. What should you look for with regard to the absorber sensor?
see if it is in firm contact with the absorber plates or the outlet manifold piping
4. Name two methods you can use to determine if a collector is operating properly.
 - a. measure pressure drop across collector
 - b. measure temperature rise through collector
5. How would you determine the best method for repair of a particular absorber coating?
follow manufacturer's literature
6. How would you correct the problem of liquid tubes pulled loose from the absorber plate?
fill in voids between tube and plate with heat transfer cement
7. What do you look for in examining insulated liquid transfer pipes?
solid mounting, no visible signs of leakage
8. Can all valves be determined to be working properly by a visual outside inspection?
No--some valves have to be disassembled to check for operation

NOTE: Solid state electronic controls are generally reliable and require maintenance only if not working. The procedures used to isolate a problem with the electronic system will be covered in the next unit on trouble-shooting. 301

MAINTENANCE CHECKLIST FOR
LENNOX LSHW- SERIES HOT WATER
SYSTEM

1. Collector Fluid Loop

- Collectors--clean glass cover with soft cloth, mild soap or detergent and clean rinse water.
- Air Vent--check for clean float and seal. Air vent will "sputter" if there is any debris caught in the unit.
- Transfer Fluid--check pH by draining a few drops of fluid from the jacket drain valve into a cup and insert pH test paper into fluid. If 8 or above, fluid is OK. If below 7.9, drain and flush collector loop and refill with 50-50, ethylene glycol-distilled water.
- Check system pressure and relief valve for proper operation.

2. Tank

- Check anode rod. Replace with proper rod if necessary.
- Drain the tank and flush to remove sediment.
- Check all fittings and insulation for leaks.

1. The maintenance activities listed below must be accomplished on a regular basis. Match the item in Column 1 with typical service interval required in Column 2.

a. Air Filters	1. <u>f</u> Check weekly for first-month and quarterly thereafter.
b. Liquid Filters	
c. Antifreeze Solutions	2. <u>e</u> Lubricate at fixed intervals suggested by manufacturer.
d. Blower Drive Belts	
e. Pumps	3. <u>d</u> Check annually and change if worn.
f. Liquid Levels	4. <u>c</u> Check annually, change when color indicator changes color.
	5. <u>a</u> Change monthly for the first three months.
	6. <u>b</u> Change after first month and annually thereafter.
2. What event requires the system to be checked any time the event occurs in daylight hours?
electric power fails
3. In a normal maintenance inspection, what should be checked to assure each collector array is operating efficiently?

(Student Note: Answer is not physical damage to collectors.)
The temperature at the top of each collector array should be the same and pressure drop across them should be the same.
4. How does a temperature sensor work?
It is a nickel wire would resistor, which changes its resistance value when temperature changes.
5. If the resistance of a sensor is found to be faulty, how do you correct the problem?
replace the sensor
6. If a sensor is immersed in liquid what must you do before replacing it?
drain the water level below the sensor mounting hole

Answer the study questions below.

1. The underlying cause of a solar system's failure to perform usually falls into one of four categories. Name these categories.
 1. part failure
 2. improper adjustment
 3. poor construction
 4. poor design
2. Of the four categories of malfunction listed above, one is usually the easiest to find and correct. Name this category.
part failure
3. There are four main reasons why system parts fail. Name three of these reasons.
 1. defect in manufacture
 2. used under conditions beyond their rated capacity
 3. not properly maintained
 4. worn out from usage
4. What is the danger of changing pulley ratios to greatly increase the velocity of the air blower?
may overload and burn out motor
5. What is the best method of preventing wear and tear on moving parts?
follow scheduled lubrication requirements
6. List four indicators that may tell you a system is out of adjustment.
 1. heating capacity seems to be decreasing
 2. heating is uneven and drafty
 3. operating cost is rising
 4. noise level is rising
7. List three malfunctions which may result in excess noise.
 1. worn out equipment isolators
 2. worn out pump bearings and belts
 3. loosened fasteners
8. What type of parts most often fail because they have been used beyond their rated capacity?
electrical components

Answer the study questions below.

1. The first step in trouble-shooting the proper operation of the solar control panel is to determine temperatures at the differential temperature controller and the solar aquastat controller sensor. The differential temperature measured at the controller is the difference in temperature between collector and storage.
2. The purpose of the solar aquastat controller is to limit the temperature of the fluid in the collector loop. If the temperature exceeds the set-point, what happens in the system if it is working properly?
Valve V1 is energized and fluid is directed through the purge loop
3. The collector and storage sensors provide an indication of temperature by a change in resistance. To measure the temperature difference at the differential controller, it is necessary to measure resistance across the terminals using a high resistance ohmmeter. How do you determine temperature from these readings?
use a curve of sensor resistance versus sensor temperature to obtain temperature
4. How would you determine the operating temperature at the solar aquastat sensor?
adjust the set-point until the relays operate, then observe temperature scale setting
5. You have determined differential temperature and the temperature at the collector aquastat. What is your next step in determining if there is an operating problem with these two controls?
read operating instructions to determine in which mode(s) the system should be operating, based on the measured temperatures
6. The collector sensors are changing resistance with temperature and read correctly on the chart of resistance versus temperature. However, the readings do not agree with separate temperature measurements you have made at the collectors. What must you do to correct this situation?
change sensor location on pipe or collector plate, and be sure it is making good contact

1. You have just finished installation and start-up of a liquid solar space heating system. Everything is working properly. You want to instruct the homeowner on what s/he can do to prevent or minimize the requirement for major service calls. List at least three things you might tell the customer.

Possible answers:

- a. Read carefully the homeowners manual provided
 - b. Do not adjust any settings or valves on the system
 - c. Do look for leaks and low liquid levels--call immediately if either if found
 - d. Report any changes in operating noise or operating efficiency
 - e. Perform the maintenance services required of the homeowner at the specified interval
 - f. Have professional maintenance services performed annually or as required.
-
2. A homeowner has called with a complaint that his system is costing more to operate and he is not getting heating directly from the collector on sunny days. What is the recommended four-step approach to determine the trouble?
 1. note complaint
 2. determine symptoms
 3. check cause of each symptom
 4. remedy trouble
-
3. You are checking out the customer complaint in Question 2 above. It is a clear, sunny day with outside temperature of 50° F. You use your multimeter across terminals F-G of the solar control panel and obtain a resistance of 3300 ohms. What two possible problems does this suggest to you?
 1. faulty collector sensor
 2. collector sensor not in contact with pipe or collector plate

4. A customer calls and tells you that he is not getting any air through the ducts on his heating system with either solar or auxiliary heat. You check the blower motor and find it is burned out. You also notice that someone has put a much larger U-belt pulley on the motor shaft than was originally installed. Explain to your customer the reason the blower motor failed.

Increasing the blower speed requires a big boost in motor horsepower. Changing the pulley size overloaded the motor causing it to burn out.

5. A customer complains that he is not getting any heat from his system, but he has noticed that hot air always seems to be coming off the purge coil. You check the solar aquastat operation by adjusting the tankstat and high limit controller, but you do not hear any relays operate. Before checking further, what components might you suspect at this point to be faulty?

solar aquastat, tank aquastat, high limit controllers, relays

6. Later you find that the high limit controller, all relays, and both the aquastat and tankstat are working properly, but all working fluid is still being diverted through the purge coil. What is the problem?

Valve 1 (dual control valve) is stuck.

7. If specific symptoms are not known in advance, what is the first step in trouble-shooting proper operation of the solar control panel?

determine differential temperature by measuring resistance across points E-F and F-G; then, convert to temperature reading using resistance-temperature chart

8. After you have found the specific faulty components and fixed or replaced them, what should you do as a final step before completing your work?

check complete system operation on a mode-by-mode basis